Choosing our words:

Lexical competition and the involvement of attention in spoken word production

Vitória Magalhães Piai

To Rob, my scientific father,
who taught me to be passionate about science
while remaining a critical thinker

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Contents

CHAPTER 1

General Introduction

Speaking is one of our most highly exercised psychomotor skills (Levelt, 1989). Seemingly simple and effortless, the production of language relies not only on precise motor preparation and execution (Hickok, 2012), but also on fast and accurate linguistic processes, such as the activation of concepts and lexical representations in long-term memory (Indefrey & Levelt, 2004; Levelt *et al.*, 1999). Selecting words from long-term memory, known as lexical selection, is a fundamental aspect of producing words, and it is at the core of the work presented here.

Studies investigating lexical selection in spoken word production have made extensive use of the picture-naming paradigm. This line of investigation builds upon the following two ideas: (1) the picture represents the concept to be expressed, and (2) retrieving the picture name requires access to representations stored in memory. This paradigm has been extremely useful in advancing our knowledge about cognitive processes involved in speaking. The work developed in this dissertation builds upon an existing theoretical framework of spoken word production (Levelt *et al.*, 1999), and its implementation in WEAVER++ (e.g., Roelofs, 1992, 1993, 1997, 2003). I outline the model in the next section, discussing in more detail the aspects that are relevant for the study of lexical selection. Next, I introduce the experimental paradigm that I used throughout the studies in this dissertation and the main findings from this paradigm in the literature that form some of the key evidence for this theoretical framework. Once the foundation has been laid, I then turn to an important set of recent challenges that the theory has faced.

1.1 A Model of Spoken Word Production

According to the theoretical framework within which the present dissertation is situated, information about words is stored in a large associative network, which is part of declarative memory. A condition-action rules system, part of procedural memory, determines what happens with the activated information depending on the task goal (Roelofs, 1992, 2003).

Conceptually driven word retrieval (e.g., naming the picture of a cat) involves the activation of nodes for lexical concepts, lemmas (syntactic lexical forms), morphemes, phonemes, and syllable motor programmes in this network (Levelt *et al.*, 1999; Roelofs, 1992, 2003). Reading a word aloud, in turn, can proceed through the mapping of input word forms (e.g., CAT in print) directly onto output word forms (phonemes) without the need for access to lexical concepts and to syntactic lexical forms. Due to this direct form-to-form mapping, a shorter network distance separates input from output in reading, whereas in naming, activation has to travel longer distances because the mapping is dependent on concepts and syntactic word representations. In WEAVER++, activation spreads from one level to the next, with each node sending only a portion of its activation to connected nodes. As a result, the activation in the network decreases with network distance. An example of spreading activation in a lexical network is exemplified in Figure 1.1.

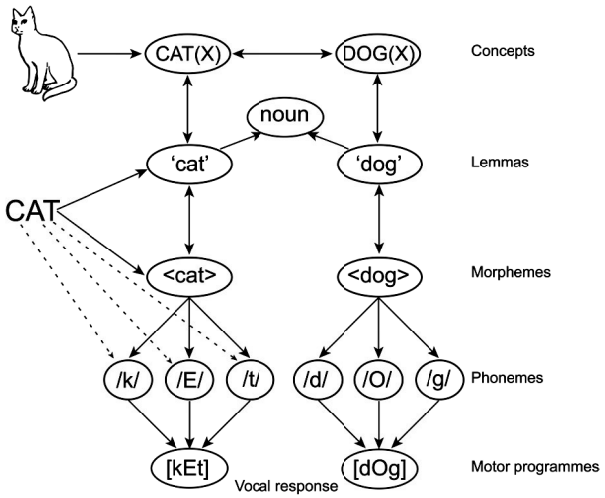

Figure 1.1: Example of the lexical network of WEAVER++. The spreading of activation is indicated by filled arrows. The dashed arrows indicate grapheme-to-phoneme correspondences. In the figure, E stands for [æ] and O stands for [ɔ].

According to the model, perceived pictures have direct access to conceptual representations (e.g., CAT(X) in Figure 1.1). When naming a picture (e.g., of a cat), the representation of the concept CAT(X) will be activated and selected. However, since that concept node is associated with other nodes in the network (e.g., DOG(X) and other animals), activation will spread to these other nodes and their corresponding lemmas (see Figure 1.1). For lexical selection in particular, this means that the selection of the target word (lemma) 'cat' will happen in the context of other activated words (lemmas). A target lemma will only be available for selection if its activation level exceeds that of other lemmas by some critical difference, the selection threshold. Moreover, the actual selection of the target in a particular moment in time equals the ratio of its activation to that of the other lemmas, the "Luce" ratio (Luce, 1959). So, according to this theoretical framework, 'cat' will be selected in a **competitive** context. More specifically, the time it takes to select 'cat' depends on the selection threshold and on the ratio of activation of 'cat' to the total activation of all co-activated words (the Luce ratio). In short, semantically related words compete for selection.

1.1.1 Experimental paradigm: picture-word interference

Behavioural evidence for multiple lexical activation and competition comes from studies of picture naming in which the amount of lexical competition is manipulated by simultaneously presenting distractor words (e.g., Rosinski, 1977; Schriefers *et al.*, 1990). These distractor words can be semantically related (e.g., a picture of a cat combined with the word *dog*), unrelated (pictured cat, word *pen*), or identical (pictured cat, word *cat*) to

the picture name. An example of such stimuli is shown in Figure 1.2. A common finding in picture-word interference studies is that picture naming response time (RT) is longer in the related than in the unrelated condition, an effect commonly referred to as the *semantic interference effect* (e.g., Roelofs, 1992; Schriefers *et al.*, 1990). Moreover, picture naming RTs are also typically longer in the related than in the identity condition, in the present work referred to as the *Stroop-like effect* (e.g., Glaser & Düngelhoff, 1984; Piai *et al.*, 2012b).

Figure 1.2: Example of picture-word stimuli. Semantically related stimuli (left) share the same semantic category, here animals. Unrelated stimuli (middle) are not semantically nor phonologically related. For identical stimuli (right), the distractor word is the picture name.

The dynamics of lexical activation and competition in the picture-word interference task is illustrated in Figure 1.3. According to the theory (e.g., Levelt *et al.*, 1999; Roelofs, 1992, 2003), a picture (e.g., of a cat) activates multiple lexical candidates that are semantically related via the conceptual connections (e.g., 'cat', 'dog', 'horse'). In particular, the picture will prime the distractor word (e.g., *dog*), referred to as reverse priming (La Heij *et al.*, 1990; Neumann, 1986), and the distractor word will prime the picture name. Accordingly, a semantically related distractor word receives further activation from the picture and is therefore a stronger competitor to the picture name than an unrelated distractor word (e.g., *pen*), which is not activated by the picture. These two cases are presented in Figure 1.3 for semantically related picture-word stimuli (left panel) and unrelated stimuli (right panel). The thick arrows indicate the first stages of the spreading activation given the picture-word stimuli. The shaded representations are the ones on which lexical selection operates. The enhanced competition in the related condition is indicated by darker shading. The enhanced competition in the related condition prolongs the duration of word selection for semantically related picture-word pairs relative to unrelated pairs, explaining the semantic and Stroop-like interference effects in the RTs. Thus, according to the theory of competitive lexical selection, the semantic interference and Stroop-like effects in picture-word interference arise at the stage of lexical selection.

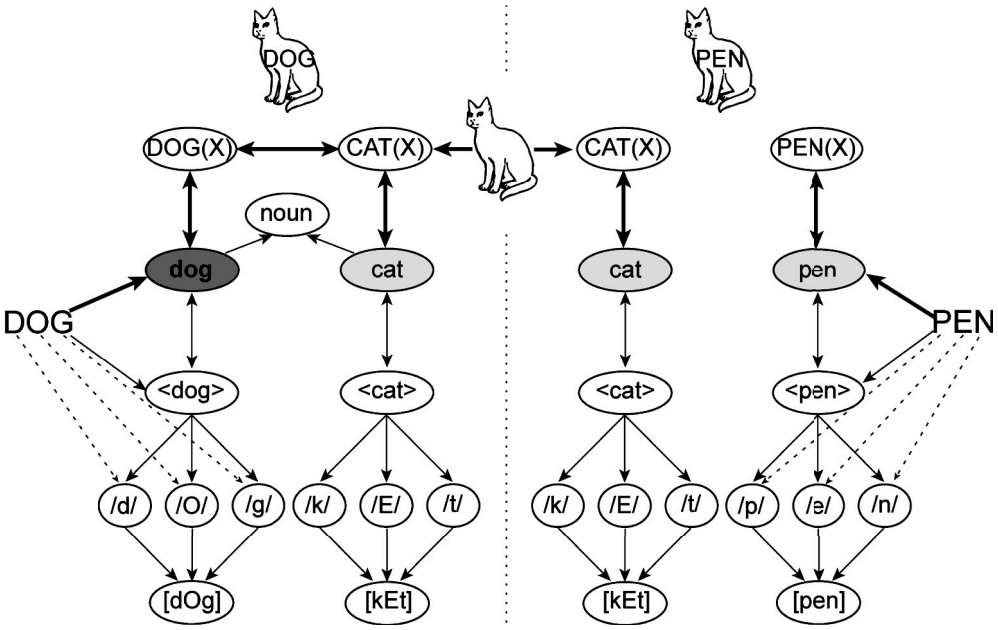

Figure 1.3: Example of the lexical network of WEAVER++ for picture-word stimuli. The network's state is shown for semantically related stimuli in the left panel and for unrelated stimuli in the right panel. Thick arrows indicate the first stages of the spreading activation. Shaded representations are the ones on which lexical selection operates. Darker shading indicates the enhanced competition. In the figure, E stands for [æ] and O stands for [ɔ].

1.2 Challenges to the Competition Hypothesis

Recently, the account of lexical-selection-by-competition has been challenged by two sets of findings. The first challenge was presented by a series of findings suggesting that the semantic interference effect arises *after* lexical selection (e.g., Finkbeiner & Caramazza, 2006b; Janssen *et al.*, 2008; Mahon *et al.*, 2007). From this observation, an alternative account has been put forward, known as the *Response Exclusion Hypothesis* (Finkbeiner & Caramazza, 2006a,b; Janssen *et al.*, 2008; Mahon *et al.*, 2007; Miozzo & Caramazza, 2003). According to this account, the semantic interference effect arises after lexical selection, close to articulation onset. Production-ready representations are kept in an output buffer, which is capable of holding only one representation at a time. As visual and auditory distractor words may be available to the articulators before picture names (e.g., Roelofs, 2003), the distractor word of a picture-word stimulus will be the first item to fill the output buffer. However, since the task is to produce the picture name, the distractor word needs to be excluded from the buffer before picture naming can take place.

Crucially, the response exclusion account assumes that the exclusion process is guided by response-relevant criteria. If the distractor word shares some feature with the picture name that is relevant to the response to be given, excluding the distractor from the output buffer will become more difficult. This cost prolongs picture naming RTs relative to picture-distractor pairs that do not share response-relevant features. For example, for the left stimulus in Figure 1.2, a response-relevant criterion would be the semantic category of the picture (cat), i.e., an animal. Given that the distractor word *dog* is also an animal, the distractor word will meet the response-relevant criterion and, therefore, excluding the articulatory code for the distractor word *dog* from the buffer will take longer relative to excluding the articulatory code for a semantically unrelated distractor like *pen*. Thus, according to this hypothesis, the prolonged picture-naming RTs in the related condition arise in the articulatory buffer. As such, it is argued, the activation level of co-activated words has no influence on how long it takes for a target word to be **selected**. This claim implies that models assuming a competitive mechanism for word selection are incorrect. Chapters 2, 3, and 4 will address the existing evidence for this alternative account.

The second challenge to the competition hypothesis was presented by experiments employing a dual-task procedure to examine at which stage during spoken word production the semantic interference effect emerges (Ayora *et al.*, 2011; Dell'Acqua *et al.*, 2007). From these experiments, it was concluded that the semantic interference effect arises *before* lexical selection, although no account was provided explaining why the semantic interference effect emerges during pre-selection stages nor what the process of lexical selection would be like in this case. Chapters 5 and 6 will address the existing evidence for this alternative account.

Importantly, as will be argued in this dissertation, the findings put forward as posing a challenge to the lexical-selection-by-competition hypothesis are problematic in light of the evidence that attentional demands interact with lexical selection processes. What I mean by attention is briefly outlined below, but how it may interact with speaking will be discussed in more detail in Chapters 2, 3, 5, and 7.

1.3 An Umbrella Called Attention

The concept of attention is central to the study of cognition. Yet, research on attention has had to explain not only attentional phenomena, but also what attention *is*. I am aware of the discussion on how the term attention should be defined (e.g., Fernandez-Duque & Johnson, 2002; Johnston & Dark, 1986), including whether it should be defined and used at all (see Anderson, 2011). In this dissertation, however, I will stay close to the umbrella term *attention* designating three functions and their respective networks: alerting, orienting, and executive control (e.g., Petersen & Posner, 2012; Posner & Petersen, 1990).

The alerting network has been described as a system involved in sustained vigilance or alertness during tasks. The orienting network has been associated with the

capacity to move towards and select a (spatial) location in order to prioritise sensory input. Finally, put very broadly, the executive-control (or 'attentional control') network supports the control and coordination of processes during the performance of complex cognitive tasks. More specifically, the active maintenance of goal-relevant information, as well as the control over memory retrieval and the selection among competing representations, are among the functions associated with the executive-control network (e.g., Engle & Kane, 2003).

1.3.1 Attention for speaking

Being a such well-practised activity, it feels as if speaking, and selecting the words we want to produce, happens automatically, placing no demands on any type of cognitive resource nor on non-linguistic processing mechanisms (Levelt, 1989). Yet, evidence has accumulated that certain linguistic processes required for speaking draw on attentional, non-automatic processing (see for review Roelofs & Piai, 2011). Take, for example, our ability to talk to someone while, at the same time, performing another task, such as driving (Kubose *et al.*, 2006; Strayer & Johnston, 2001) or identifying an object only by touch (Oomen & Postma, 2001). To a greater or lesser extent, we all feel at times that speaking in these situations is hampering the other activity, or vice versa, which is evidenced by impoverished performance in the concurrent task: We become more accident-prone and have more disfluencies in our utterances.

The evidence that speaking is not fully automatic, but rather draws on some kind of resource, is now substantial, be it anedoctal or coming from experimental investigations (reviewed in e.g., Roelofs & Piai, 2011). The use of this "resource" by a speaker, and especially in relation to how that speaker chooses his or her words, is one of the central issues in this dissertation.

1.4 Further Considerations

1.4.1 The timing of word production processes

Estimates of the timing of processing stages underlying word production have been provided by meta-analyses (Indefrey, 2011; Indefrey & Levelt, 2004). These estimates are shown in Figure 1.4 for three global stages in standard word production (see for details Indefrey, 2011; Indefrey & Levelt, 2004), which form the relevant division of stages for the current debate in the literature (i.e., semantic interference is a *pre-lexical*, a *lexical*, or a *post-lexical* effect). Pre-planning processes are cognitive processes that are task specific and take place before core word production processes (e.g., visual word recognition in word reading and object recognition in picture naming). Conceptual preparation, which is included in the pre-planning stages, entails the activation and selection of some lexical concept to be expressed. Word planning comprises the stages of lexical selection and

word-form encoding, which is further divided into morphological, phonological, and phonetic encoding (Levelt *et al.*, 1999). In the final stage of phonetic encoding, phonological syllables are turned into motor programmes.

According to the time estimates, based on an average naming latency of 600 ms (upper panel of Figure 1.4), word planning starts around 200 ms after picture onset. The motor plans for articulation reach the articulatory buffer around 145 ms prior to articulation onset (Indefrey, 2011; Indefrey & Levelt, 2004). In the picture-word interference task, however, mean naming latencies tend to be longer than 600 ms, normally ranging between 700 to 800 ms (or even longer, depending on the task context). The longer RTs in picture-word interference brings to question whether standard estimates should be considered, as shown in the upper panel of Figure 1.4, or whether the estimates should be rescaled to longer naming latencies (Indefrey, 2011), as shown in the lower panel of Figure 1.4. It is plausible to assume that the presence of visual distractors prolongs perceptual processing, delaying the onset of word planning (Indefrey, 2011; Piai *et al.*, 2012b), which speaks in favour of rescaling. There are different ways in which the rescaling can be conducted. One simple - albeit not optimal (see Indefrey, 2011) - way, is the linear rescaling of the duration of all processing stages. Using a proportional rescaling of the timing estimates to a mean naming latency of 800 ms (a very rough average of the mean naming latencies presented in the following chapters) yields the rescaled estimate of word planning onset around 270 ms after picture presentation, shown in the lower panel of Figure 1.4. Alternatively, there are reasons to deviate from linear proportional rescaling (Indefrey, 2011), but this option requires a precise identification and time estimation of the processes prolonging the naming latencies. Due to the lack of precise estimations, I opted for using linear rescaling in this dissertation, especially for the earlier processes. The timing of motor-programme preparation in picture-word interference, however, should remain quite unchanged relative to standard picture naming, i.e., around 145 ms prior to articulation onset. This assumption is based on the fact that both tasks require naming responses for which motor programmes have to be prepared. Factors known to influence motor-programme preparation in speech production are, for example, the number of syllables and the phonetic features of the target word (e.g., A.S. Meyer *et al.*, 2003; D.E. Meyer & Gordon, 1985). Such factors are unlikely to differ systematically between responses in standard picture naming and picture-word interference.

According to the Response Exclusion Hypothesis (Finkbeiner & Caramazza, 2006a,b; Janssen *et al.*, 2008), the interference effect emerges when "a production-ready representation corresponding to the distractor word must be purged from the single-channel output buffer" (Janssen *et al.*, 2008, p. 250), or "at the point of deciding which of two articulatory programs should be excluded from the output buffer in order that the correct response may be produced" (Finkbeiner & Caramazza, 2006a, p. 1033). As can be seen in Figure 1.4, based on the existent time estimates (Indefrey, 2011; Indefrey & Levelt, 2004), this buffer *cannot* be reached earlier than about 145 ms before articulation onset. This timing argument is especially important in Chapter 4. Similarly, according

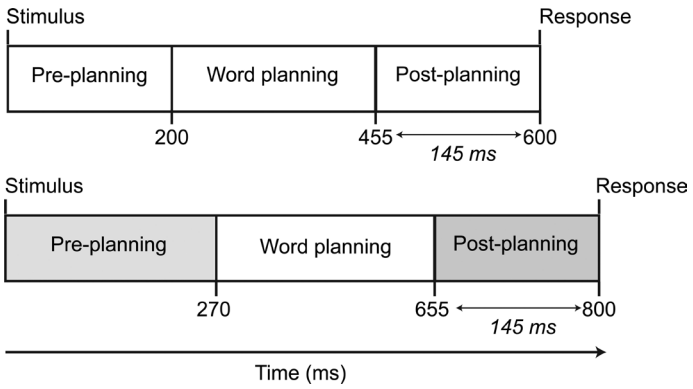

Figure 1.4: Time estimates of pre-planning, word planning, and post-planning processes in word production for a mean RT of 600 ms (upper panel) and 800 ms (lower panel). The light-shaded area indicates the hypothesised pre-lexical locus of the semantic interference effect (Dell'Acqua *et al.*, 2007). The dark-shaded area indicates the hypothesised post-lexical locus of the semantic interference effect (Finkbeiner & Caramazza, 2006a,b; Janssen *et al.*, 2008; Mahon *et al.*, 2007; Miozzo & Caramazza, 2003).

to the hypothesis that effects in the picture-word interference task arise *before* lexical selection (Dell'Acqua *et al.*, 2007), distractors should modulate processing before 200-270 ms. This timing argument is especially important in Chapter 6.

1.4.2 Response time distribution analysis

The use of response time distribution analysis in the field of language production does not have a long history. This type of analysis, however, can be very fruitful in revealing effects that may otherwise be concealed in averaged RT analysis due to a mixture of different underlying effects. For example, it has been shown that an absent effect in the mean RTs may be the result of opposing (facilitation and interference) effects in different parts of the RT distribution, cancelling each other out in the mean RTs (Heathcote *et al.*, 1991).

Two types of distribution analyses are used in different chapters of this dissertation: Vincentile and ex-Gaussian analyses. In Vincentile analysis (Ratcliff, 1979), group RT distributions are examined. For that, we rank-order the RTs for each participant in each condition and divide them into quantiles (for example, 20%). Then quantile means are computed for each participant in each condition and finally averaged across participants. In ex-Gaussian analysis, an explicit function for the shape of the distribution is fitted (e.g., Heathcote *et al.*, 1991; Luce, 1986; Ratcliff, 1979). Three parameters are generated characterising the distribution: μ and σ, reflecting the mean and standard deviation of the Gaussian portion, respectively, and τ, reflecting the mean and standard deviation of the exponential portion. Theoretically, the mean of the distribution equals the sum of μ and τ. Thus, the ex-Gaussian analysis decomposes the mean RTs into two

additive components, characterising the leading edge (μ) and the tail (τ) of the underlying RT distribution. The use of these analyses plays an important role in the arguments put forward in Chapters 2, 3, and 6.

1.5 Outline of the Dissertation

The next six chapters will address various issues related to the competition hypothesis in lexical selection. Chapter 2 examines the role of attentional control in immediate and delayed naming. This chapter is based on the evidence previously provided in the literature that the semantic interference effect is present when picture-naming responses are delayed, arguably supporting the hypothesis that the semantic interference effect arises *after* lexical selection (Janssen *et al.*, 2008). Chapter 3 investigates the role of distractor strength in the competition process. The experiments reported in this chapter were motivated by previous findings in the literature that only consciously perceived distractor words delay picture-naming responses, an observation taken to support the account that the semantic interference effect arises *after* lexical selection (Finkbeiner & Caramazza, 2006b). In Chapter 4, magnetoencephalography was used to highlight the temporal dynamics of lexical activation and competition as well as candidate brain regions involved in the process. The temporal information obtained in this study can show when brain activity is modulated as a function of the distractor word, thus possibly indicating the time window associated with the semantic interference effect.

Whereas Chapters 2, 3, and 4 are dedicated to the question of whether the semantic interference effect arises *after* lexical selection, Chapters 5 and 6 focus on previous findings suggesting that the semantic interference effect arises *before* lexical selection (Ayora *et al.*, 2011; Dell'Acqua *et al.*, 2007). In Chapter 5, a series of experiments employing a dual-task procedure is reported investigating the role of dual-task interference and attentional control in lexical selection, following previous demonstrations that the semantic interference effect is absent under certain circumstances in a dual-task setting (Dell'Acqua *et al.*, 2007). Chapter 6 also addresses the temporal aspects of distractor effects in picture naming by examining the timing of electrophysiological activity associated with the semantic interference and Stroop-like effects.

In Chapter 7, the role of attentional control in spoken word production is examined in more detail. In particular, this study employed functional magnetic resonance imaging to investigate whether brain regions involved in domain-general attentional control are also engaged during control over word planning. Finally, in Chapter 8, I will present a summary of the core findings of this dissertation and discuss their implications for the lexical competition account, as well as for the alternative accounts proposed in the literature.

1.5.1 Notes on the structure of the dissertation

The three main distractor-word manipulations used throughout this dissertation are referred to by different terms in some of the chapters, depending on the context in which the particular chapter was written. For the ease of referencing, here I list the different names used for each distractor-type condition: **related:** *categorically related, incongruent, semantic*; **identical:** *congruent, identity*; **unrelated:** *neutral*.

On a final note, there will be a certain amount of overlap in the introduction of the different chapters, which is unavoidable given that each chapter consists of a study published as an independent journal article. The bibliography is presented at the end of the dissertation, comprising the references from all chapters. Finally, tables and figures are numbered consecutively within each chapter.

CHAPTER 2

Semantic interference in immediate and delayed naming and reading: Attention and task decisions

Disagreement exists about whether lexical selection in word production is a competitive process. Competition predicts semantic interference from distractor words in immediate but not in delayed picture naming. In contrast, Janssen, Schirm, Mahon, and Caramazza (2008) obtained semantic interference in delayed picture naming when participants had to decide between picture naming and oral reading depending on the distractor word's colour. We report three experiments that examined the role of such task decisions. In a single-task situation requiring picture naming only (Experiment 1), we obtained semantic interference in immediate but not in delayed naming. In a task-decision situation (Experiments 2 and 3), no semantic effects were obtained in immediate and delayed picture naming and word reading using either the materials of Experiment 1 or the materials of Janssen et al. (2008). We present an attentional account in which task decisions may hide or reveal semantic interference from lexical competition depending on the amount of parallelism between task-decision and picture-word processing.

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I thank Hannah Ferentzi and Jil Humann for their help in running the experiments.

2.1 Introduction

Competition has been widely regarded in the cognitive neurosciences as an important mechanism in human cognition. Across different psychological domains, such as language comprehension (e.g., Norris, 1994), cognitive control (e.g., Miller & Cohen, 2001), visual perception (e.g., Desimone & Duncan, 1995), and motor control (e.g., Jeannerod, 1997), competition has been taken as a mode of operation fundamental to the workings of these cognitive processes. Similarly, in the field of spoken word production, competition has long been assumed to be the mechanism underlying lexical selection (Levelt *et al.*, 1999; Roelofs, 1992). Recently, however, Caramazza and colleagues (e.g., Finkbeiner & Caramazza, 2006a,b; Janssen *et al.*, 2008; Mahon *et al.*, 2007) argued against the assumption of competition in lexical selection in word production. In this article, we start by briefly reviewing the evidence for competition in word production and its challenge put forward by Janssen et al., based on evidence they obtained in delayed-response experiments where participants had to decide between picture naming and word reading on each trial. Next, we point out a potentially problematic characteristic of the task-decision procedure of Janssen et al. We present the results of three new experiments examining immediate and delayed picture naming and word reading and the role of task decisions.

Important evidence taken to be in favour of competition in word production comes from the semantic interference effect obtained with the picture-word interference (PWI) paradigm (e.g., Lupker, 1979; Rosinski, 1977; Schriefers *et al.*, 1990). In this paradigm, the participants' task is to name a picture while ignoring a visual distractor word superimposed onto the picture (or, in the auditory version of the PWI paradigm, while ignoring auditory distractors presented together with the picture). Participants are slower to name pictures (e.g., arm) when the distractor has a semantic categorical relation with the picture (e.g., *leg*) than when the distractor is semantically unrelated to the picture (e.g., *train*). Given that this effect only emerges when speakers have to access the picture name, as opposed to responding manually to the picture or to reading the distractor word, the semantic interference effect is taken to arise during lexical access (Schriefers *et al.*, 1990). Moreover, given that the effect is one of interference rather than facilitation, lexical selection has been taken to be a competitive process (Levelt *et al.*, 1999; Roelofs, 1992; Starreveld & La Heij, 1996). Under the lexical competition account, names corresponding to semantically related concepts become activated through spreading activation via a conceptual network and compete for selection. In the case of semantically related distractors, their activation is further increased by their presence in the input and augments the competitive process. This increased competition surfaces as longer naming latencies for pictures in the presence of semantically related distractors relative to semantically unrelated distractors. Thus competition operates such that the activation of the target node relative to the activation of other activated candidates is determinant for the accuracy and speed of selection of the target. It should be noted that the picture-word interference paradigm not only taps into lexical selection but also into

attentional mechanisms (e.g., Roelofs, 1992, 2003; Starreveld & La Heij, 1996).

Caramazza and colleagues advanced an alternative, non-competitive account for the semantic interference effect, thereby challenging the assumption of lexical competition. According to their *response exclusion* hypothesis (Finkbeiner & Caramazza, 2006a,b; Janssen *et al.*, 2008; Mahon *et al.*, 2007), the semantic interference effect arises after lexical selection, close to articulation onset. Visual and auditory distractor words are assumed to be available to the articulators before picture names are (e.g., Roelofs, 2003). According to the response exclusion hypothesis, phonologically specified production-ready representations are kept in an output buffer, which is assumed to be capable of holding only one representation at a time. When participants are presented with a picture and a distractor word simultaneously, the distractor word is the first item to fill the output buffer. In order to produce the name of the picture, the distractor word needs to be excluded from the buffer before picture naming can take place. Note that this exclusion process could involve a competition between the response occupying the buffer and the response seeking to gain access to it. However, in this case, the competition is at play at a late stage, close to articulation onset, whereas the lexical competition hypothesis maintains that competition plays a role at an earlier stage, during lexical selection.

One core assumption of the response exclusion account is that the decision process excluding a word from the output buffer has semantically interpreted information at its disposal. Excluding the distractor from the output buffer costs time and will become more difficult, hence take longer, if the distractor word shares criteria that must be met by the response to be given. Relevant criteria that must be fulfilled, in this account, include the provenance of the production-ready representation (whether it was a picture or a word), the word class, and the semantic category the representation belongs to, among other criteria. Under this view, the semantic interference effect originates from this exclusion process: Semantically related distractor words will take longer to be excluded from the buffer than will semantically unrelated words because the former share a response relevant criterion (i.e., semantic category) with the picture name.

Important evidence for the response exclusion hypothesis comes from Janssen et al. (2008). Janssen and colleagues introduced a modified version of the PWI paradigm requiring immediate and delayed responses. In a delayed-response task, participants are instructed to delay their responses until a specific cue is given. In Janssen et al.'s delayed condition, the cue to respond was the colour of the distractor word, indicating whether participants had to name the picture or read the distractor aloud. The rationale of delayed naming is that the picture name will be retrieved upon presentation of the picture but it will be withheld from production until the cue is given. Participants took part either in the delayed condition or in the immediate condition. In half of the trials, participants named the picture and in the other half of the trials, they read the distractor word aloud. For the sake of simplicity, we use the term *naming* as a shorthand for *picture naming* and *reading* for *distractor word reading* from here onwards.

To be able to assess whether participants in the delayed condition indeed prepared the naming responses, the picture-name frequency was manipulated. The frequency

effect is a well established effect in the word production literature (Balota & Chumbley, 1985; Jescheniak & Levelt, 1994; Oldfield & Wingfield, 1965): Pictures with high-frequency names are named faster than pictures with low-frequency names. However, with delays longer than 1,000 ms, the frequency effect disappears (Balota & Chumbley, 1985). This frequency effect has been shown to be a lexical effect (Bonin & Fayol, 2002; Jescheniak & Levelt, 1994). From the forty pictures used by Janssen et al., half had low-frequency names and half high-frequency names.

The lexical competition hypothesis predicts semantic interference in immediate naming but not in delayed naming. In delayed naming, the distractor will not enter in competition with the picture name for selection because the name has already been selected before the distractor is presented. In contrast, according to the response exclusion hypothesis, semantic interference should be obtained both in immediate and delayed naming because the distractor needs to be excluded from the output buffer in both cases.

In line with the predictions of the response exclusion hypothesis, Janssen and colleagues (2008) found semantic interference for both immediate and delayed naming. Moreover, the semantic interference effect in the delayed condition was accompanied by the lack of a frequency effect, which was present in immediate naming. The absence of a frequency effect in delayed naming indicates that the lexical representation of the picture name had already been retrieved when the cue to produce the picture name was given. As the authors argue, the fact that the semantic interference effect is still found in the delayed condition challenges the lexical competition account: As the picture name has been retrieved before the distractor has been presented, the latter cannot have entered the competition process. Therefore, the semantic interference effect cannot be reflecting this competition and, thus, is not informative about the properties of lexical access. On the contrary, as they argue, if semantic interference arises post-lexically due to shared response criteria, then delaying the articulation of the picture name should not matter as the distractor word still needs to be excluded from the output buffer. Consequently, one should observe semantic interference in delayed naming as well, as Janssen et al. did.

However, Mädebach and colleagues (Mädebach *et al.*, 2011), using Janssen et al.'s materials and a design nearly identical to Janssen et al.'s experiments, failed to replicate the semantic interference effect in delayed naming while obtaining the same pattern of frequency effects as Janssen et al. (Experiments 1, 3 and 5). Surprisingly, Mädebach et al. also failed to obtain semantic interference in immediate naming using Janssen et al.'s task (Experiment 5). However, the same set of materials yielded a sizeable semantic interference effect using the standard PWI paradigm (Experiments 2, 4 and 6). Mädebach et al. concluded that the semantic interference effect found by Janssen et al. is not of the same nature as the interference effect usually found with the PWI paradigm. Accordingly, using results obtained with Janssen et al.'s task to reject the competition account is not justified. However, Mädebach and colleagues did not test delayed naming without task decisions. Moreover, they do not explain why the semantic interference effect is absent in immediate naming using Janssen et al.'s paradigm. According to the competition hypothesis, competition should have played a role in lexical selection in

immediate naming, thereby leading to longer RTs in the semantically related condition than in the unrelated condition. In the next section, we describe an account that explains the difference in results between studies with respect to immediate naming in terms of the task decisions required in the paradigm of Janssen et al.

2.2 A Task-Decision Account

In a standard PWI experiment, participants know they have to name the pictures. Janssen et al. (2008), however, used a task-choice procedure (cf. Besner & Care, 2003) in which participants have to decide which task to perform online and at every trial. The colour of the distractor word determines whether the picture has to be named or whether the distractor word has to be read aloud. This change in the paradigm appears to be so minimal that it makes one believe it still is straightforwardly comparable to the standard PWI paradigm. However, the fact that task decisions need to be made raises an issue of attentional control, namely how task decisions and picture-word processing are coordinated.

Based on findings obtained in the context of the psychological refractory-period (PRP) paradigm used in examining dual-task performance (Pashler, 1994; Pashler & Johnston, 1989), it has been argued that, when participants plan words in the context of a concurrent task, they set a criterion concerning the amount of overlap allowed between the tasks (Meyer & Kieras, 1997a,b; Roelofs, 2007, 2008a). So although two stimuli may be identified in parallel, some processes of each task cannot occur simultaneously, forcing certain computations for the second task to wait until computations for the first task are accomplished (see also Sigman & Dehaene, 2008). The period during which processing of the second task has to wait for the other task is commonly known as *cognitive slack*. Some effects usually observed in a single-task situation may disappear in a dual-task situation because the processing time associated with that effect is absorbed into the cognitive slack (e.g., Pashler & Johnston, 1989). The PRP paradigm and the task-choice paradigm differ in the extent to which participants know what task to perform at a specific point in time (see Besner & Care, 2003): The task is known beforehand in the PRP case whereas in the task-choice paradigm, choices are made at every trial. It has been shown that this decision process is not trivial, requires attention, and can take hundreds of milliseconds to be completed (Paulitzki *et al.*, 2009).

In Janssen et al.'s paradigm, there are two major processing streams: The language processes, involved in picture naming and word reading, and a task-decision process, responsible for deciding which task to perform. Allowing the language processes to proceed with the input of both the picture and the distractor until the end, i.e., until articulation, would be problematic since only one response is required. So clearly, the language processes need to be suspended at a certain point until participants know which task to perform. However, they only know which task to perform after the task-decision process, based on colour identification, has been completed. This means that although

participants may allow some amount of picture-word processing to run in parallel with the task-decision process, at a certain point the language processes have to be suspended until the task-decision process is finished. A candidate moment at which participants may choose to suspend the language processes is when lexical selection has taken place, and before word-form encoding starts (see Figure 2.1 ; word form encoding refers to the processes of morphological encoding, phonological encoding, and phonetic encoding). The suggestion of this moment as a potential suspension point is motivated by the observation that word-form encoding in both picture naming and reading aloud has been shown to require attention (Reynolds & Besner, 2006; Roelofs, 2008a). Since the task-decision process also requires attention (Paulitzki *et al.*, 2009), it is plausible that participants would suspend the naming and reading processes before word-form encoding to be able to allocate attentional resources to the task-decision process.

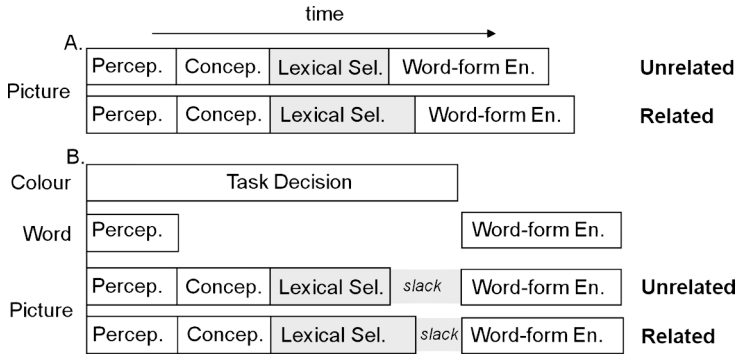

Figure 2.1: Schematic illustration of the slack logic. Each box represents one processing stage. Panel A illustrates picture naming without task decisions. Panel B illustrates picture naming or word reading with a concurrent task-decision process. Percep. = perception; concep. = conceptualising; lexical sel. = lexical selection; word-form en. = word-form encoding. The distractor conditions are given in bold to the right of the figure.

The competition account assumes that semantic interference arises because of the delay in selecting a word in the semantically related condition relative to the unrelated condition. Panel A of Figure 2.1 shows the assumed stages of picture naming and the source of differential RTs for the semantically related and unrelated conditions in the standard PWI paradigm. Indefrey and Levelt (2004) estimated that lexical selection in picture naming may be completed within some 250 ms after picture onset. Moreover, Paulitzki et al. (2009) estimated that task decisions may take some 200-300 ms. If the task-decision process takes longer than the language processes up to and including lexical selection, the language processes will have to wait for the output of the task-decision process. That the language processes have to wait for the task-decision process follows naturally from the fact that participants can only respond after they know which task they have to perform. Consequently, lexical competition may be resolved during

the cognitive slack created by the task-decision process, as Panel B of Figure 2.1 shows. Once the task-decision process has delivered an output and participants know they should continue with picture naming, this process will resume from word-form encoding onwards. However, the difference in RT between the semantically related and unrelated conditions caused by competitively selecting a word will have been absorbed into the cognitive slack and will no longer be reflected in the net RTs, as Mädebach et al. observed. If there is no cognitive slack to absorb the longer lexical selection duration for semantically related distractors (e.g., because task decisions are completed before lexical selection is finished), semantic interference will be visible in the RTs, as Janssen et al. observed. Similarly, it has been observed that manual responding to a tone diminishes semantic interference effects from distractor words in concurrent picture naming at short compared to long SOAs in a PRP experiment (Dell'Acqua *et al.*, 2007). As Dell'Acqua et al. argued, this finding suggests that manual responding to a tone may create cognitive slack, which may absorb the semantic interference effect.

In short, our hypothesis is that semantic effects will surface in the RTs if the duration of the stages in the picture naming process up to and including lexical selection in the related condition is longer than the duration of the task-decision process. Note that the amount of cognitive slack required to absorb lexical selection differences does not have to be large: Semantic context effects usually have a magnitude of 30 ms to 40 ms. This means that a difference of some 40 ms between the task-decision and the picture naming processes is already enough to render the effect measurable or not. If task decisions took slightly less time in the study of Janssen et al. than in that of Mädebach et al., the difference in results between these studies is readily explained. Note that the task-decision account is compatible with the lexical competition account, but not with the response exclusion account. This is because a response cannot be excluded before the task is known, thus response exclusion cannot take place in parallel with the task-decision process. Consequently, semantic interference arising from response exclusion cannot be absorbed into the slack created by the task-decision process.

To sum up, the present study focuses on two major issues: the role of task decision in immediate picture-naming and whether semantic effects are present in delayed picture-naming. Note that these two issues are tightly related: Janssen et al. make a claim against competitive lexical selection by showing semantic interference in delayed naming. But in their experiments, they used a task-decision paradigm. Accordingly, investigating either only task decision or semantic effects in delayed naming addresses the issues raised by the evidence of Janssen et al. only partially. Consequently, these two issues are better studied in combination.

2.2.1 Plan of the present study

In Experiment 1, participants did not have to make task decisions: They were instructed to name the pictures only and to ignore the distractor words. Pictures were named in both immediate and delayed conditions by the same participants (Janssen et al. tested the

conditions between participants). Given that there are no task decisions, the competition hypothesis predicts semantic interference in immediate but not in delayed naming. In contrast, according to the response exclusion account, semantic interference should be obtained in both immediate and delayed naming.

In Experiment 2, we introduced task decisions and we tested for semantic interference in both immediate and delayed naming using the design and materials of Janssen et al. (2008) translated into Dutch. We recorded both naming and reading RTs (Janssen et al. and Mädebach et al. report only naming RTs). Half the trials required naming and the other half required reading. Participants performed both immediate and delayed tasks. According to our task-decision account, depending on the relative speed of picture naming and task-decision processes, semantic interference should be present or absent in immediate naming. Moreover, semantic interference should always be absent in delayed naming and in reading (Glaser & Düngelhoff, 1984; Glaser & Glaser, 1989; Roelofs, 1992, 2003). In contrast, under the response exclusion account, semantic interference should be obtained for immediate and delayed naming, and reading in the delayed condition. According to the response exclusion hypothesis, written words obligatorily enter the articulatory buffer and overwrite buffered responses (Finkbeiner & Caramazza, 2006b). However, this would entail that prepared and buffered picture names are overwritten by the written word and that the picture name has to be planned again in the delayed condition. This should yield both a semantic interference effect and a frequency effect, contrary to what Janssen et al. (2008) observed. Therefore, we assume that written words engage the response exclusion process rather than overwrite buffered naming responses. This predicts semantic effects in word reading.

In Experiment 3, we tested semantic interference in delayed naming and reading with the same materials as in Experiment 1. We increased the proportion of naming trials in the experiment from 50% (as in previous studies and in Experiments 1 and 2) to 75%, making it even more likely that participants would prepare their naming responses. Again, we recorded both naming and reading RTs. According to the competition hypothesis, semantic interference should be found neither in naming nor in reading. According to the response exclusion account, on the contrary, semantic interference should be found for both reading and naming, especially in the 75% naming condition.

To extend our analyses and to increase their sensitivity, besides the standard statistical tests based on averaged RTs, we also conducted RT distributional analyses on the data of the three experiments. The use of averaged RTs has the disadvantage of concealing a possible mixture of different underlying effects. Latency distribution analyses may reveal these tradeoffs (e.g., Yap & Balota, 2007; Lamers & Roelofs, 2007; Roelofs, 2008c) as they examine the shapes of whole distributions. We performed both Vincentile and ex-Gaussian analyses. In Vincentile analyses (see Ratcliff, 1979), group RT distributions are examined. Ex-Gaussian analysis, in turn, characterises an RT distribution by assuming an explicit function for the shape of the distribution (e.g., Heathcote *et al.*, 1991; Luce, 1986; Ratcliff, 1979; Yap & Balota, 2007). The ex-Gaussian analysis provides three parameters characterising a distribution: μ and σ, reflecting the mean and standard

deviation of the Gaussian portion respectively, and τ, reflecting the mean and standard deviation of the exponential portion. The mean of the whole distribution equals the sum of μ and τ (with a few milliseconds rounding error in estimations).

Heathcote et al. (1991) showed that effects that are absent in mean RTs may nevertheless be present as opposing effects in the ex-Gaussian components (e.g., as facilitation in μ and interference in τ, cancelling each other out in the mean RTs). Thus, it is important to assess whether effects that are absent in mean RTs, as the competition hypothesis predicts for semantic interference in delayed naming and reading, are nevertheless present in components of the RT distributions. Vincentile and ex-Gaussian analyses allow one to explicitly test for these possibilities. To our knowledge, this study is the first one to extensively use different RT distribution analyses to investigate the semantic interference effect in the PWI paradigm (for an analysis of semantic facilitation, see Roelofs, 2008c).

2.3 Experiment 1

In our first experiment, no task decisions had to be made: Participants always named the pictures while ignoring the distractor words. To ascertain that participants were nevertheless processing the distractor word in delayed naming, a distractor-word verification task was introduced: At the end of each trial, a verification word was shown. Participants had to indicate whether the verification word and the distractor were the same or not by pressing one of two buttons. To make the immediate and delayed conditions as similar as possible, the verification task was introduced for both conditions. Different from Janssen et al. (2008), our participants always performed both immediate and delayed naming.

Janssen et al. presented the pictures continuously until trial offset in their delayed condition. We opted for having the presentation duration of the pictures restricted to 250 ms. With a restricted presentation of the picture, participants are pressed to select the picture name at picture presentation. Moreover, they are less likely to re-engage in lexical selection since the picture is no longer visible to them.

In the absence of task decisions, the competition hypothesis predicts semantic interference in immediate but not in delayed naming, whereas the response exclusion account predicts semantic interference in both immediate and delayed naming.

2.3.1 Method

Participants. Eighteen young adult participants (2 male) from the participant pool of Radboud University Nijmegen participated in the experiment for compensation of 7.5 Euros. All participants were native speakers of Dutch with normal or corrected-to-normal vision.

Materials and design. Thirty-two pictures were selected from the picture database of the Max Planck Institute for Psycholinguistics, Nijmegen, together with their basic-level names in Dutch. This selection consisted of pictures of objects from eight different

semantic categories with four objects pertaining to each category. A list of the materials can be found in Appendix A.1. Additionally, four pictured objects were selected as practice items. These were taken from two semantic categories which were different from the eight experimental categories. All pictures were white line drawings on a black background, scaled to fit into a frame of 10 cm x 10 cm. The words were presented in font Arial size 36.

Each target picture was combined with a word from the same semantic category (related condition) and with a word from a different semantic category (unrelated condition) by re-pairing the pictures with different distractors, yielding 64 picture-distractor pairs. This first independent variable is referred to as distractor type (related, unrelated). The manipulation of distractor type was varied within participants and within items. Distractor words were presented in white and they were members of the response set. The second independent variable was response mode (immediate, delayed). Three different inter-stimulus intervals (ISI) were used: 0 ms (immediate naming condition) and 1,000 ms or 1,500 ms distractor post-exposure (delayed naming condition). The 64 picture-distractor pairs appeared once at 1,000-ms and once at 1,500-ms ISIs, and twice at 0-ms ISI. Trials were blocked by response mode (i.e., immediate vs. delayed). In the case of the delayed naming condition, both ISIs were presented in random order.

Verification words were presented in yellow (RGB: 255,255,0) on a black background. For each trial, the verification word could be either identical to the distractor (identical condition) or different (different condition). In the latter case, the verification word was always semantically unrelated to both the picture and the distractor but still belonged to the response set. The 64 picture-distractor pairs in the immediate naming condition were combined once with 64 verification words from the identical condition, and once with a word from the different condition. Similarly, thirty-two pairs from the 1,000-ms ISI and 32 pairs from the 1,500-ms ISI conditions were combined with a verification word of the identical condition and the remaining 32 pairs in each of these two ISIs, with a verification word of the different condition. In total, each response mode block consisted of 128 trials, which were presented in random order with one unique list per participant. The items were randomised using Mix (van Casteren & Davis, 2006) following two constraints: A given picture or a given distractor could not appear in consecutive trials. Participants took part in both the immediate and the delayed naming conditions and the order of the response mode conditions was counterbalanced across participants.

Procedure and apparatus. Participants were seated in front of a computer monitor (screen resolution: 1280x1024), approximately 50 cm away from it. The presentation of stimuli and the recording of responses were controlled by Presentation Software (Neurobehavioral Systems, Albany, CA). Vocal responses were measured with a voice key. Before the experiment, participants were familiarised with the pictures and the names to be used in the experiment. They were instructed to name the picture upon the presentation of the distractor word and to give a manual response indicating “yes” or “no” upon the presentation of the verification word. Next, a block of eight practice trials was presented

according to the response mode condition, followed by the experiment proper.

For the immediate block, participants were instructed to name the picture and to ignore the distractor word. For each trial in the immediate condition, a black screen was presented for 500 ms followed by the display of the picture-distractor pair, which remained on the screen for 250 ms. A black screen followed for 2,250 ms. Next, the verification word appeared on the screen for 250 ms followed by a black screen for 2,250 ms. For the delayed block, participants were instructed to name the picture only upon presentation of the distractor word, which always appeared after the target picture. For each trial, a black screen was presented for 500 ms followed by the presentation of the picture. The picture remained on the screen for 250 ms followed by a black screen for 1,000 ms or 1,500 ms, depending on the ISI of the respective trial. Next, the distractor word was presented for 250 ms followed by a black screen for 2,250 ms. Then the verification word was displayed for 250 ms followed by a black screen for 2,250 ms. An example of the trial structures can be found in Figure 2.2. The registration of the vocal and manual responses started as soon as the distractor word and the verification word, respectively, were displayed on the screen and lasted 2,500 ms. The target pictures, the distractors and the verification words always appeared in the centre of the screen. The whole experimental session lasted approximately 30 minutes.

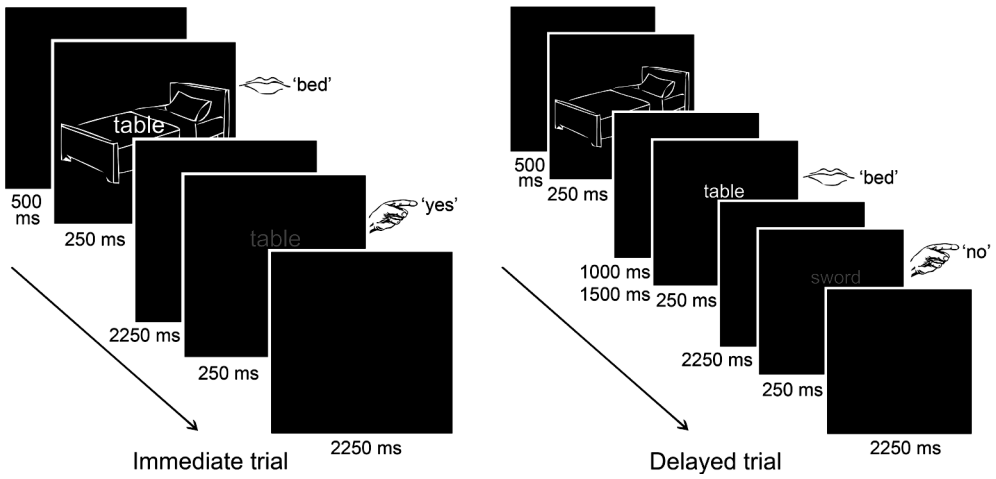

Figure 2.2: Example of the structure of an immediate trial and a delayed trial of Experiment 1. The verification word was always yellow in the experiment, whereas here it is exemplified in grey. The mouth indicates the vocal response; the finger indicates the manual response.

Analysis. After each trial, the experimenter evaluated the participants' vocal responses. Responses which contained a disfluency, a wrong pronunciation of the word, a wrong response word, or triggering of the voice key by a sound which was not the participant's response were coded as errors and subsequently excluded from the statistical analyses

of the naming RTs. Naming RTs and verification RTs shorter than 100 ms were also excluded from the analyses. RTs were submitted to by-participant (F_1) and by-item (F_2) analyses of variance with response mode and distractor type as independent variables. Furthermore, *minF'* (Raaijmakers *et al.*, 1999) was computed for the effects of distractor type only if both F_1 and F_2 reached significance. Additional post-hoc frequency analyses were conducted with by-participant and by-item ANOVAs with response mode, frequency of the pictures' names and distractor type as independent variables. For the relevant comparisons, involving distractor type, 95% confidence intervals are provided in addition to the results of the ANOVAs. Errors were submitted to logistic regression analyses. Ex-Gaussian parameters were analysed with dependent t-tests. Since we predict semantic interference in immediate naming, one-tailed t-tests were used.

2.3.2 Results

Mean naming RTs. Table 2.1 shows the means of the naming RTs for the immediate condition and the collapsed delayed condition. First, we split the naming RTs into trials with correct vs. incorrect subsequent verification responses. No effect of accuracy in the naming RTs was found nor any interactions with response mode or distractor type, all Fs < 1. Therefore naming RTs were analysed independently of accuracy in the verification task. For the two delayed naming conditions (ISIs 1,000 ms and 1,500 ms), there was no main effect of ISI, no main effect of distractor type, and no interaction between distractor type and ISI, all Fs < 1. Therefore, the ISIs of 1,000 ms and 1,500 ms were collapsed in subsequent analyses of the delayed condition. Moreover, response mode sequence, i.e. whether participants started with immediate or delayed naming, did not reach significance in any analysis nor did it enter in any interactions, all ps $> .1$. Therefore, we collapsed the data from the two different sequences.

Table 2.1: Mean response time (M) in milliseconds, percent error (PE), and mean ex-Gaussian parameter estimates in milliseconds

Response mode/Distractor type	M	PE	μ	σ	τ
Immediate					
Related	895	9.0	720	69	176
Unrelated	856	7.9	699	57	161
Difference	39	2.1	21	12	15
Delayed					
Related	535	6.9	393	70	144
Unrelated	538	6.2	384	71	155
Difference	-3	.7	9	-1	-11

Pictures were named faster in the delayed than in the immediate condition, $F_1(1,17) = 201.62$, $MSE = 10381$, $p < .001$, $F_2(1,31) = 710.8$, $MSE = 5214$, $p <$

.001. Pictures in the semantically related condition were named more slowly than in the unrelated condition, $F_1(1,17) = 11.42$, $MSE = 493$, $p = .004$, $F_2(1,31) = 8.86$, $MSE = 1317$, $p = .006$, $minF'(1,47) = 4.99$, $p = .03$. More importantly, a significant interaction between response mode and distractor type was found, $F_1(1,17) = 10.61$, $MSE = 633$, $p = .005$, $F_2(1,31) = 13.76$, $MSE = 1115$, $p < .001$. Simple effect analyses showed that the semantic interference effect was present for immediate naming, $F_1(1,17) = 27.07$, $MSE = 456$, $p < .001$, 95% *CI* [22, 52], $F_2(1,31) = 17.36$, $MSE = 1548$, $p < .001$, 95% *CI* [20.9, 61.1], $minF'(1,48) = 10.58$, $p = .002$; but not for delayed naming, $F_1(1,17) < 1$, 95% *CI* [-19.8, 16.6], $F_2(1,31) < 1$, 95% *CI* [-18, 12.4].

Error percentages for naming. Table 2.1 shows the mean error percentages for the immediate condition and the collapsed delayed condition. Logistic regression analyses of the error percentages revealed that the odds of a correct answer in delayed naming were 1.99 times higher than in immediate naming, β *coefficient* = .69, *S.E.* = .22, *Wald Z* = 3.19, $p = .001$. Distractor type was not a significant predictor in the model, nor was the interaction, ps $> .4$.

Verification RTs. In immediate naming, the mean RTs for the correct button-press responses were 653 ms in the semantically related and 640 ms in the unrelated condition. In delayed naming, the means were 687 ms in the semantically related and 686 ms in the unrelated condition. The verification RTs were overall 40 ms slower in the delayed condition than in the immediate condition, $F_1(1,17) = 6.7$, $MSE = 4679$, $p = .019$, $F_2(1,31) = 34.76$, $MSE = 2008$, $p < .001$. No interactions were found between distractor type and response mode, both Fs < 1.

Error percentages for verification. For immediate naming, the mean error percentages for verification responses were 39.5 in the semantically related and 38.5 in the unrelated condition. For delayed naming, the percentages were 2.0 in both conditions. The odds of a correct verification in delayed naming are 27.4 times higher than in immediate naming, β *coefficient* = 3.32, *S.E.* = .22, *Wald Z* = 15.33, $p < .001$. Distractor type was not a significant predictor in the model, nor was the interaction, ps $> .9$.

Distributional analyses of naming RTs. Figure 2.3 gives the Vincentised cumulative distribution curves per response mode and distractor type. The figure shows that the semantically related condition was slower than the unrelated condition throughout the latency range in immediate naming, whereas the distractor conditions did not differ from each other regardless of naming latency in delayed naming. Thus, the semantic interference observed in the mean RTs in immediate naming is the result of a shift of the complete RT distribution towards responding more slowly in the related compared to the unrelated condition. Moreover, semantic interference in delayed naming is absent across the whole latency range.

Table 2.1 shows the means of the ex-Gaussian parameters μ, σ and τ. Dependent t-tests revealed semantic interference in the μ parameter in immediate naming, $t(17) = 1.9$, $p = .037$, whereas in delayed naming the effect was absent, $p > .2$. All remain-

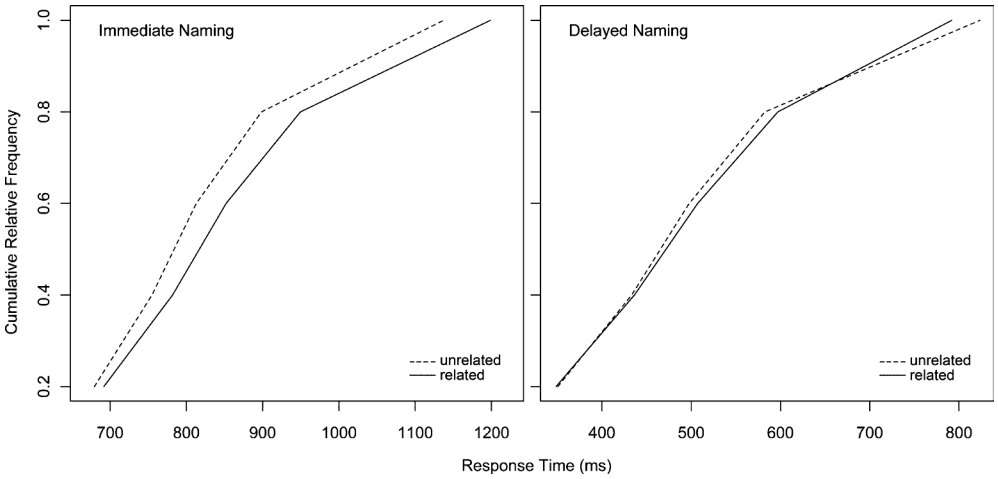

Figure 2.3: Vincentised cumulative distribution curves for the related and unrelated conditions in immediate naming (left panel) and delayed naming (right panel) of Experiment 1.

ing t-tests were not significant, all ps > 1. Thus, the ex-Gaussian analyses confirm the conclusion from the Vincentile analyses: The semantic interference in immediate naming is the result of distributional shifting, whereas delayed naming yields no semantic effect across the whole latency distribution.

Post-hoc frequency analysis. Although the frequency of the pictures' names was not an independent variable manipulated in the design of the experiment, post-hoc frequency analyses were conducted by acquiring frequency counts from CELEX (Baayen *et al.*, 1993) for the pictures' names used in the experiment. Not all pictures' names in our materials could be analysed because the range of frequencies for the high and low conditions obtained with the median split were not discrete enough. Therefore, a new cut-off was established, with 11 items per condition (range low-frequency condition: 4.9-22.8 per million; range high-frequency condition: 81.8-303.2 per million).

Pictures in the high-frequency condition were named overall 22 ms faster than in the low-frequency condition, $F_1(1,17) = 9.56$, $MSE = 1751$, $p = .006$, $F_2(1,21) < 1$. The interaction with response mode was also significant, $F_1(1,17) = 7.21$, $MSE = 2304$, $p = .016$, $F_2(1,21) = 1.51$, $MSE = 5058$, $p = .233$. Planned comparisons showed that the frequency effect was only reliable in immediate naming: Pictures in the high-frequency condition were named 48 ms faster than pictures in the low-frequency condition, $F_1(1,17) = 12.47$, $MSE = 2655$, $p = .002$; whereas in delayed naming, pictures in the low-frequency condition were named 4 ms faster, $F_1(1,17) < 1$. Interactions with distractor type were not significant, $F_1(1,17) < 1$.

2.3.3 Discussion

In Experiment 1, we tested for the presence of a semantic effect in both immediate and delayed naming with the standard PWI paradigm. Contrary to Janssen et al. (2008) and similar to Mädebach et al. (2011), we failed to replicate the semantic interference effect in delayed naming whereas we obtained a sizeable semantic interference effect in immediate naming with our materials. Moreover, we tested post-hoc for a frequency effect, which was found only in immediate but not in delayed naming, suggesting that participants prepared their responses in delayed naming. The fact that the frequency effect was not significant in the by-item analysis is probably because our materials were not selected on the basis of their frequency but on the basis of semantic categories instead. The lack of frequency and semantic effects in delayed naming corroborates the hypothesis that the picture name was prepared at picture presentation and retained from articulation until the presentation of the cue.

The RT distributional analyses corroborated the findings of the mean RT analyses. A shift in the entire latency distribution was found as a function of distractor type only in immediate naming. Moreover, semantic interference was reflected in the μ parameter of the ex-Gaussian function for immediate naming, but not for delayed naming.

To address the concern that the distractor word was not relevant for the task at hand in the delayed condition, we used a verification task. Participants were much more accurate in the verification task in the delayed condition than in the immediate condition. The high error rate in immediate naming suggests that planning the picture name goes at the expense of not attending enough to the distractor in order to perform the verification task. However, the semantic interference effect in immediate naming was independent of accuracy in the verification task, indicating the robustness of the effect.

The time parameters used in this experiment are somewhat different from the ones in Janssen et al. By restricting the presentation of the picture, we could better control participants' lexical access in delayed naming. Although it is unlikely that the difference in these parameters is the cause of the discrepancy in the results, we cannot rule out this possibility at this point. Experiments 2 and 3, however, address this concern more directly. The findings of Experiment 1 show that, without task decision, semantic interference is obtained in immediate naming but not in delayed naming. These findings are in accordance with the competition hypothesis, but go against the predictions of the response exclusion account.

2.4 Experiment 2

In the second experiment, we introduced task decisions and tested for the semantic interference effect in both immediate and delayed naming and reading using the design and materials of Janssen et al. (2008) translated into Dutch. Note that, contrary to Janssen et al., our participants performed both delayed and immediate tasks and we recorded and analysed the word reading RTs as well (Janssen et al. only reported picture naming

RTs). We analysed reading RTs for the following reason. According to the response exclusion hypothesis, semantic interference should be obtained not only in naming but also in reading in the delayed condition because the task-irrelevant response needs to be removed from the response buffer in both cases. Upon presentation of the picture, the response to the picture will be buffered. In a word reading trial, this response needs to be excluded from the buffer in order for it to accommodate the response to the distractor. If the two responses share response relevant criteria such as their semantic category, a semantic interference effect should be found for word reading. In contrast, according to the competition hypothesis, semantic interference should always be absent in both immediate and delayed reading because words can be read aloud via a shallower route that does not require access to lemma information (Roelofs, 1992, 2003). In particular, words can be read by mapping orthographic lexical forms onto phonological lexical forms or by applying grapheme-to-phoneme conversion rules (cf. Coltheart *et al.*, 2001).

According to our task-decision account, in case of task decisions, semantic interference should be present or absent in immediate naming depending on the relative average speed of picture naming and task-decision processes. According to the competition hypothesis, if participants prepare the picture name at picture presentation, no semantic interference should be found in delayed naming. The presence or absence of semantic interference should hold not only for the mean RTs but also for the whole RT distributions. According to the response exclusion hypothesis, however, semantic interference should always be found in both delayed and immediate naming and in reading in the delayed condition.

2.4.1 Method

Participants. Twenty-eight students (5 male) from the participant pool of Radboud University Nijmegen participated in the experiment for compensation of 5 Euros. All participants fulfilled the same criteria as for Experiment 1.

Materials and design. The same 40 pictured objects as in Janssen et al. (2008) were used. Our pictures were taken from the database of Snodgrass and Vanderwart (1980) or from our own database. The pictures were white line drawings on a black background, scaled to fit into a frame of 10 cm x 10 cm. Basic-level names in Dutch were determined, which coincided with the direct Dutch translation from Janssen et al.'s pictures' names, except for the item "lips" (changed into the Dutch word *mond* 'mouth'). A list of the materials can be found in Appendix A.2. The 40 pictures were combined with 40 semantically related distractor words, which were the Dutch translations of Janssen et al.'s distractors (except the word "cards", translated into the singular form, the word "kidney", translated into *lever* 'liver', and the word "flask", translated into *thermos*). For the semantically unrelated condition, we used the same semantically unrelated pairs as Janssen et al., with their respective Dutch translations. The words were presented in font Arial size 36. Each experimental list contained the 80 picture-distractor pairs, which were presented once in the naming condition and once in the reading condition, yielding

160 trials per response mode. The items were randomised using Mix (van Casteren & Davis, 2006) following the same constraints on the randomisation as in Experiment 1, with the addition of one constraint: The same task did not occur in more than three consecutive trials. There was one unique randomisation per participant per response mode. Participants took part in both the immediate and the delayed conditions and the order of response mode blocks was counterbalanced across participants.

Procedure and apparatus. The apparatus and the set up were identical to Experiment 1. Participants were instructed to either name the picture (green distractor, RGB: 0,160,0) or to read the distractor out loud (blue distractor, RGB: 0,0,200) depending on the colour of the distractor. Moreover, specific instructions were given for each response mode condition. Next, participants were given a booklet to get familiarised with the pictures and the names to be used in the experiment. A naming training phase followed in which the 40 pictures used in the experiment were presented once in the centre of the screen with their respective names 3 cm below the picture. Participants were instructed to read aloud the names of the pictures. Before the start of each block, a practice session was administered. The trial structure of the practice phase was identical to the trial structure of the experimental block that would be administered next. Four pictures from four different categories, none of which were used as experimental stimuli, were selected for the practice sessions. The four pictures were combined with a semantically related and an unrelated distractor, totalling 8 trials, half of which were naming trials and half of which reading trials, presented in random order.

The trial structures were similar to Janssen et al. (2008). A trial of the immediate condition started with the presentation of the picture-distractor pair for 500 ms. A black screen followed for 2,000 ms. In the delayed condition, a trial started with the presentation of the picture for 1,000 ms followed by the superposition of the distractor word. The picture and the distractor remained together on the screen for 500 ms. A black screen followed for 2,000 ms. An example of the trial structures can be found in Figure 2.4. The whole experimental session lasted approximately 25 minutes. The registration of the vocal responses started as soon as the distractor word was displayed on the screen and lasted 2,500 ms. The target pictures and the distractors always appeared in the centre of the screen.

Analysis. Both picture naming trials and word reading trials were analysed in the same way as in Experiment 1 (except for the verification task, which was not part of Experiment 2). The response mode sequence was treated as a between-subjects and within-items variable and task (reading/naming), response mode and distractor type as within-subjects and within-items.

2.4.2 Results

Mean naming and reading RTs. Table 2.2 shows the means of the naming and reading RTs for the immediate and the delayed conditions. Response mode sequence did

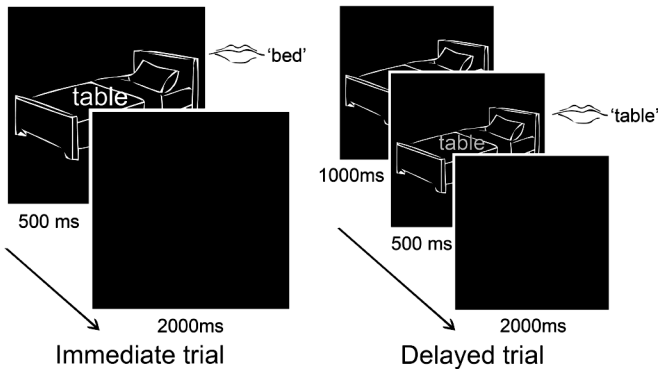

Figure 2.4: Example of the structure of a delayed and an immediate trial in Experiment 2. The distractor words were green or blue in the experiment. Here, for exemplification, grey distractors indicate the reading trials (blue in the experiment) and white distractors indicate the naming trials (green in the experiment).

not enter in any interactions; therefore, we collapsed the data from the two sequences. Participants were 114 ms faster in the delayed block than in the immediate block, $F_1(1,27) = 27.72$, $MSE = 26129$, $p < .001$, $F_2(1,39) = 656.1$, $MSE = 3337$, $p < .001$. Overall naming was 123 ms slower than overall reading, $F_1(1,27) = 152.8$, $MSE = 5597$, $p < .001$, $F_2(1,39) = 333.35$, $MSE = 7445$, $p < .001$. Task and response mode interacted, $F_1(1,27) = 44.56$, $MSE = 7759$, $p < .001$, $F_2(1,39) = 165.1$, $MSE = 6292$, $p < .001$. Reading was significantly faster than naming in both the immediate block, $F_1(1,27) = 195.34$, $MSE = 5857$, $p < .001$, $F_2(1,39) = 320.66$, $MSE = 10498$, $p < .001$; and in the delayed block, $F_1(1,27) = 7.56$, $MSE = 7499$, $p = .01$, $F_2(1,39) = 47.733$, $MSE = 3239$, $p < .001$. The distractor type effect did not reach significance as a main effect, $F_1(1,27) < 1$, 95% *CI* [-5.7, 9.2], $F_2(1,39) < 1$, 95% *CI* [-6.3, 11.7]; nor entered in significant interactions, all ps $> .1$.

Error percentages for naming and reading. For the error percentages, shown in Table 2.2, no predictor was significant in the logistic-regression model, all ps $> .1$.

Distributional analyses of naming and reading RTs. RT distribution analyses confirmed the absence of a semantic effect for both reading and naming in delayed and immediate conditions. Figure 2.5 gives the Vincentised cumulative distribution curves for naming and reading per response mode. The figure shows that the RT curves for the two distractor types are completely overlapping for both immediate and delayed naming and reading in the immediate condition, and nearly overlapping for reading in the delayed condition.

Table 2.2 shows the means of the ex-Gaussian parameters μ, σ, and τ. Dependent t-tests revealed no significant effects for any of the parameters, all ps $> .2$. Thus, the

Table 2.2: Mean response time (M) in milliseconds, percent error (PE), and mean ex-Gaussian parameter estimates in milliseconds

Task/Response mode/Distractor type	M	PE	μ	σ	τ
Naming					
Immediate					
Related	925	4.8	746	67	179
Unrelated	915	3.9	742	72	175
Difference	10	.9	4	-5	4
Delayed					
Related	730	3.0	580	83	152
Unrelated	723	3.4	579	82	146
Difference	7	-.6	1	1	6
Reading					
Immediate					
Related	719	2.7	582	70	137
Unrelated	717	2.4	581	67	137
Difference	2	.3	1	3	0
Delayed					
Related	678	2.4	554	52	125
Unrelated	687	3.2	571	61	118
Difference	-9	-.8	-17	-9	7

ex-Gaussian analyses confirmed the absence of semantic effects in naming and reading, as already suggested by the Vincentile analyses.

Post-hoc frequency analysis. Post-hoc frequency analyses were conducted in the same way as for Experiment 1. Only 26 names were included in the analyses in order to have a clear separation of frequency ranges (range low-frequency condition: 1.5-8.8 per million; range high-frequency condition: 81.8-1037.5 per million). A main effect of frequency was found, with pictures in the high-frequency condition being named overall 37 ms faster than in the low-frequency condition, $F_1(1,27) = 22.34$, $MSE = 3740$, $p < .001$, $F_2(1,24) = 7.62$, $MSE = 5168$, $p = .011$. The interaction with distractor type was not significant, Fs < 1. The interaction with response mode was significant, $F_1(1,27) = 8.34$, $MSE = 3259$, $p = .008$, $F_2(1,24) = 5.4$, $MSE = 3190$, $p = .029$. Planned comparisons showed that, in immediate naming, pictures with high-frequency names were named 60 ms faster than pictures with low-frequency names, $F_1(1,27) = 22.47$, $MSE = 4603$, $p < .001$, $F_2(1,24) = 8.14$, $MSE = 6681$, $p = .009$; whereas in delayed naming, a non-significant difference of 15 ms was found, $p > .09$.

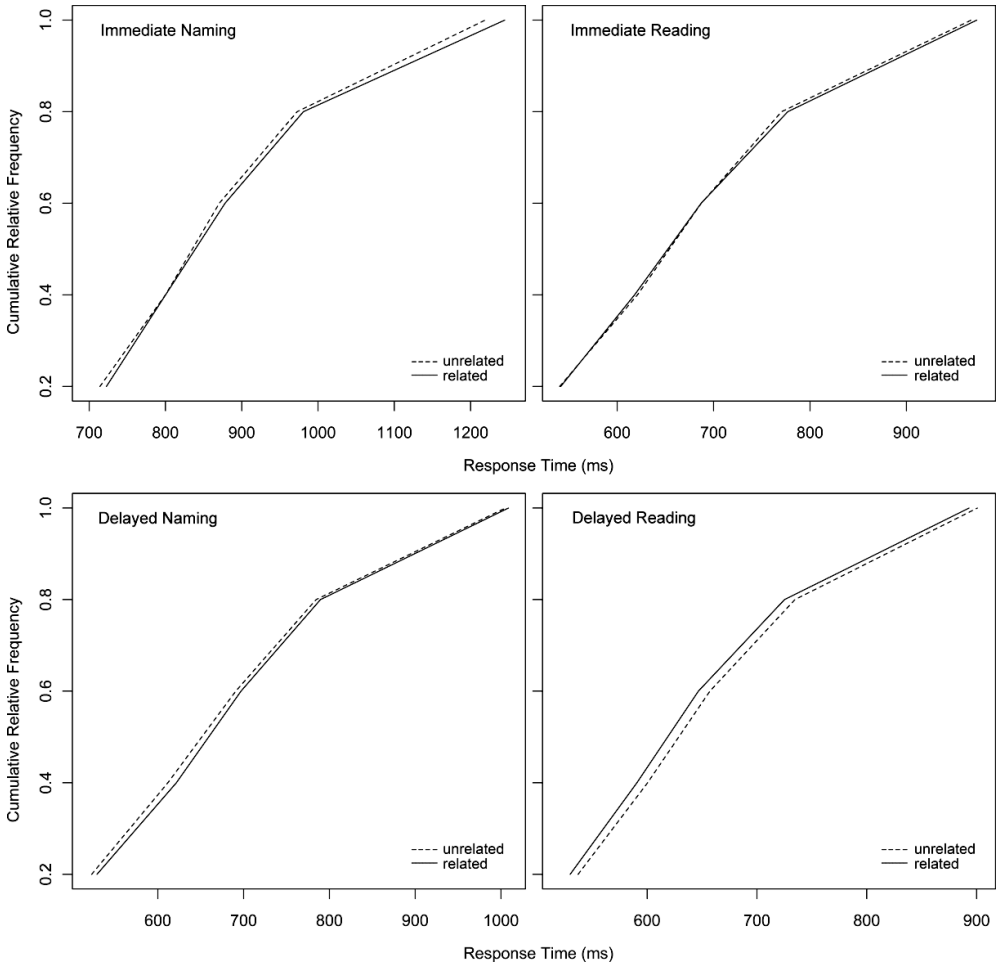

Figure 2.5: Vincentised cumulative distribution curves for the related and unrelated conditions in immediate naming (top left panel), immediate reading (top right panel), delayed naming (bottom left panel) and delayed reading (bottom right panel) of Experiment 2.

2.4.3 Discussion

The results of Experiment 2 show that word reading was performed faster than picture naming, which is in accordance with the idea that words can be read aloud via a shallower route than pictures can be named (see, e.g., Roelofs, 1992, 2003). The semantic interference effect, however, was absent not only in delayed naming but also in immediate naming, an observation also made by Mädebach and colleagues (2011). Semantic interference was also absent in reading, contrary to the prediction derived from the response exclusion. Complementary to the mean RT analyses, Vincentising and ex-Gaussian analyses con-

firmed the absence of semantic interference throughout the RT distributions. Post-hoc frequency analyses indicated that pictures in the high-frequency condition were named faster than pictures in the low-frequency condition in immediate naming only, replicating the well-known frequency effect (Oldfield & Wingfield, 1965) also found by Janssen et al. (2008). This suggests that participants generally prepared the picture name at picture presentation.

Experiments 1 and 2 failed to show any semantic interference in delayed naming, either with or without task decisions. A failure to replicate, however, is more credible with more experiments supporting it. Therefore, in Experiment 3, only the delayed condition was tested.

2.5 Experiment 3

Although we did not find a frequency effect in delayed naming in the post-hoc analysis in Experiment 2, we cannot be entirely certain that our participants prepared the picture name on the same number of trials as the participants of Janssen et al. (2008) presumably did. To address this concern, we increased the proportion of naming trials from 50% (as in previous studies and in Experiments 1 and 2) to 75%. Half of the participants had to name the pictures in 75% of the trials and read the distractors aloud in only 25% of the trials. The other half of the participants had the reverse proportion. If participants have to mostly name the picture throughout the experiment (i.e., the 75% naming condition), they are really invited to prepare the picture name on each trial. This should yield the semantic interference effect predicted by the response exclusion hypothesis. The reverse proportion (25% naming, 75% reading) was used to assess the effectiveness of the proportion manipulation. If the proportion manipulation is effective, naming RTs should be shorter for the 75% than for the 25% condition. We used the same materials as for Experiment 1 because this set of materials yielded a considerable semantic interference effect in immediate naming in that experiment. According to the competition hypothesis, semantic interference should be found neither in naming nor in reading. According to the response exclusion account, on the contrary, semantic interference should be found for both reading and naming, especially in the 75% naming condition.

2.5.1 Method

Participants. Twenty-eight students (9 male) from the participant pool of Radboud University Nijmegen participated in the experiment for compensation of 5 Euros. All participants fulfilled the same criteria as for Experiments 1 and 2.

Materials and design. The same 64 picture-distractor word pairs from Experiment 1 were used. The colours used for the reading and naming trials were identical to Experiment 2. The proportion manipulation was used as a between-subject factor. In the 75% naming-25% reading condition, the 64 picture-distractor pairs were repeated once with

the distractors coloured blue and three times with the distractors coloured green. In this way, 75% of the experimental list consisted of picture naming trials and only 25% of the trials were word reading trials. In the 25% naming-75% reading condition, the reversed proportion was used. Each experimental list contained 256 items, which were randomised using Mix (van Casteren & Davis, 2006). The same constraints on the randomisation as in Experiment 2 were used. There was one unique randomisation per participant. Fourteen participants took part in the 75% naming-25% reading condition and the other 14 participants took part in the 25% naming-75% reading condition. All participants performed only the delayed response task.

Procedure and Apparatus. The apparatus and the set up were equal to Experiments 1 and 2. Before the experiment, participants were familiarised with the pictures and the words used in the experiment. They were instructed to either name the picture or to read the word out loud depending on the colour of the word. Moreover, specific instructions were given to participants depending on the proportion condition they were assigned to in order to already bias them towards a "picture naming" or a "word reading" mode. For example, participants in the 25% naming-75% reading condition were told that they would have to read the word most of the time. A block of 32 practice trials preceded the experiment proper with the experimental pictures presented once with a semantically unrelated distractor not used in the experiment. The proportion manipulation was also built into the practice session. The trial structure was the same as for the delayed trials of Experiment 2.

Analysis. Both picture naming trials and word reading trials were analysed in the same way as for Experiment 2. The proportion manipulation was treated as a between-subjects and within-items variable, and task (reading/naming) and distractor type as within-subjects and within-items variables.

2.5.2 Results

Mean naming and reading RTs. Table 2.3 shows the means of the naming and reading RTs for both proportion manipulations. In the 75% naming-25% reading condition, participants were on overage 109 ms faster than participants in the other condition, $F_1(1,26) = 11.08$, $MSE = 44614$, $p = .003$, $F_2(1,31) = 725.4$, $MSE = 1584.50$, $p < .001$. Overall naming was 20 ms faster than overall reading, $F_1(1,26) = 19.62$, $MSE = 3343.41$, $p < .001$, $F_2(1,62) = 88.23$, $MSE = 1681.57$, $p < .001$. More importantly, however, naming RTs were shorter in the 75% than in the 25% condition [task by proportion interaction, $F_1(1,26) = 67.89$, $MSE = 1672.13$, $p < .001$; $F_2(1,31) = 65.6$, $MSE = 2262$, $p < .001$], showing that participants prepared their naming responses according to the proportion condition they were assigned to. A main effect of distractor type was, however, absent, $F_1(1,26) < 1$, 95% CI [-8.58, 7.10], $F_2(1,31) < 1$, 95% CI [-25.2, 21.1], and so were the interactions, $ps > .1$.

Error percentages for naming and reading. Table 2.3 shows error percentages

for the naming and reading responses for both proportion manipulations. For the error percentages, only task was a significant predictor in the model, β *coefficient* = -1.19, *S.E.* = .334, *Wald* $Z = 3.57$, $p < .001$: The odds of a correct response in reading are 3.29 times higher than in naming.

Table 2.3: Mean response time (M) in milliseconds, percent error (PE), and mean ex-Gaussian parameter estimates in milliseconds

Task/Proportion Manipulation/Distractor type	M	PE	μ	σ	τ
Naming					
75% naming					
Related	556	3.1	430	53	127
Unrelated	564	2.6	435	63	129
Difference	-8	.5	-5	-10	-2
25% naming					
Related	787	6.2	634	69	150
Unrelated	783	5.6	649	92	134
Difference	4	.6	-15	-23	16
Reading					
25% reading					
Related	596	2.0	510	43	86
Unrelated	609	4.5	508	39	100
Difference	-13	-2.5	2	4	-14
75% reading					
Related	650	2.7	539	53	111
Unrelated	641	3.2	535	43	106
Difference	9	-.5	4	10	5

Distributional analyses of naming and reading RTs. RT distribution analyses confirmed the absence of a semantic effect. Figure 2.6 gives the Vincentised cumulative distribution curves for naming and reading per distractor condition and proportion manipulation. For naming, the RT curves for the two distractor conditions are completely overlapping, confirming the absence of a semantic effect across Vincentiles. For the reading task, small effects seem to be present in the tail of the distribution. The effect tends to be one of semantic interference in the 25%-reading condition and facilitation in the 75%-reading condition.

Table 2.3 shows the means of the ex-Gaussian parameters, μ, σ, and τ. Dependent t-tests revealed no significant differences for any of the parameters, all ps $> .1$. Thus, the ex-Gaussian analyses confirm the absence of a semantic effect in naming and in reading, as already suggested by the Vincentile analyses.

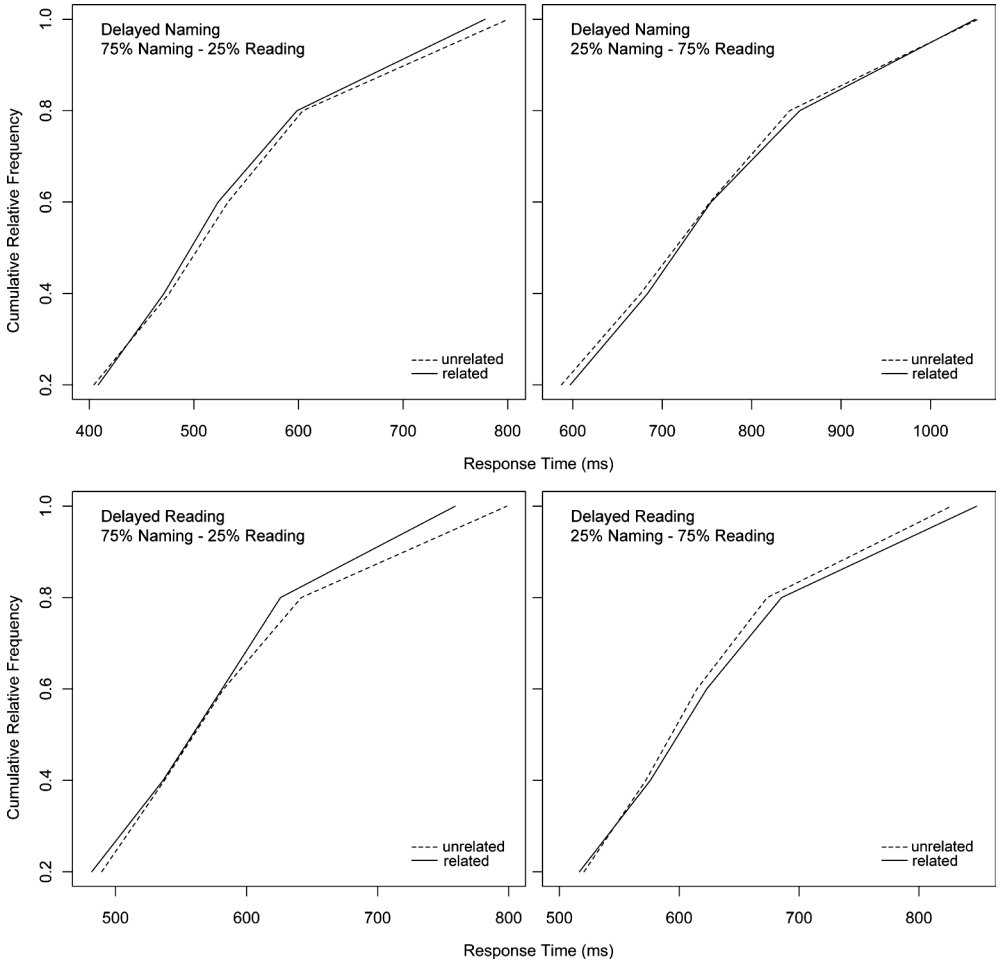

Figure 2.6: Vincentised cumulative distribution curves for the related and unrelated conditions in delayed naming (top left panel) and delayed reading (bottom left panel) for the 75% naming-25% reading condition, and in delayed naming (top right panel) and delayed reading (bottom right panel) for the 25% naming-75% reading condition of Experiment 3.

2.5.3 Discussion

In this experiment, we observed that naming and reading RTs varied as a function of the proportion manipulation, such that performance was faster for the task participants had to execute most of the time. Independently of this sensitivity, however, the semantic interference effect remained absent in both naming and reading and throughout the RT distributions. The absence of semantic interference in delayed naming corresponds to the findings of Experiments 1 and 2 and to what Mädebach et al. (2011) observed, and differs

from what Janssen et al. (2008) obtained. Moreover, the absence of semantic interference in delayed reading goes against the predictions of the response exclusion hypothesis.

2.6 General Discussion

Disagreement exists about whether lexical selection in word production is a competitive process. Lexical competition models predict semantic interference from distractor words in immediate but not in delayed picture naming. In contrast, Janssen et al. (2008) obtained semantic interference in delayed naming when participants had to decide between naming the picture or reading the distractor word aloud depending on its ink colour. However, Mädebach et al. (2011) obtained no semantic interference in delayed naming, even though the effect was present in a standard immediate-naming experiment for another group of participants. Moreover, Mädebach et al. failed to obtain semantic interference in immediate naming using the task-decision procedure of Janssen et al. In the present article, we raised two issues that might be of concern: task decision in immediate picture-naming and the semantic interference effect in delayed picture-naming. Regarding the former, we presented a task-decision account which holds that semantic interference from lexical competition may be hidden depending on the relative speed of task-decision and picture-word processes. Our first two experiments examined the merits of this account. Concerning our second aim, we tested for semantic interference in delayed picture-naming in all three experiments, in an attempt to replicate Janssen et al.'s findings. We performed RT distributional analyses in all three experiments.

In Experiment 1, task decisions did not play a role as participants only named pictures whereas the distractor words were never read aloud. Given that there is no task decision in this experiment, the competition hypothesis predicts semantic interference in immediate but not in delayed naming. In contrast, according to the response exclusion account, semantic interference should be obtained in both immediate and delayed naming. We obtained semantic interference in immediate but not in delayed naming. These observations held for both mean RTs and RT distribution components. These results support the lexical competition account of semantic interference and challenge the response exclusion account.

The inclusion of a verification task at the end of each trial of Experiment 1 could have influenced the results of this experiment by affecting participants' performance in the task. However, the size of the semantic interference effect found for immediate naming is very similar to interference effects previously found using a comparable set of materials without the verification task, reported in Roelofs (2006, Experiment 1B) and Roelofs (2007, Experiment 1). Moreover, Experiments 2 and 3 tested delayed naming without the verification task and replicated the findings of Experiment 1 for delayed naming. So although the verification task might have affected performance in picture naming in general, it does not seem to have affected the results obtained.

In Experiment 2, we introduced task decisions and we tested for semantic interference in both immediate and delayed naming and reading using the design and materials

of Janssen et al. (2008) translated into Dutch. The response exclusion hypothesis predicts semantic interference in both immediate and delayed naming and in reading in the delayed condition. The competition hypothesis, however, predicts that competition will play a role in lexical selection only in immediate naming but never in delayed naming. According to our task-decision account, semantic interference from lexical competition in immediate naming may be hidden depending on the relative speed of task-decision and picture-naming processes, which may create cognitive slack, absorbing semantic interference from competition. We obtained no semantic interference for both immediate and delayed naming. Moreover, according to the competition hypothesis and contrary to the response exclusion hypothesis, we did not find semantic interference in reading.

In Experiment 3, we made a further attempt to replicate Janssen et al. Since we did not manipulate frequency directly in Experiments 1 and 2, we could not be certain that our participants were preparing the picture name as often as the participants did in the study of Janssen et al. So we manipulated the proportion of naming and reading trials. The idea was that if participants had to name the picture in the majority of the trials, they would be very likely to prepare the picture name as soon as possible. This should increase the chance that the experiment yields the semantic interference that is predicted by the response exclusion hypothesis. We observed that naming RTs varied as a function of trial proportions such that participants were always faster in naming in the 75% than in the 25% condition, attesting the effectiveness of the proportion manipulation. Semantic interference, however, was absent regardless of the proportion of naming and reading trials and across the whole RT distribution. Furthermore, no semantic interference was found in the reading RTs. These findings go against the predictions of the response exclusion hypothesis.

Taken together, the results of Experiments 1 and 2 support our account that task decisions may hide semantic interference from lexical competition depending on the relative speed of task-decision and picture-word processes. As we already noted, our task-decision account of the absence of semantic effects in immediate naming, if adopted by the response exclusion account, would result in very contradictory assumptions. Task decision can only hide semantic interference if the effect occurs within 200-300 ms after picture-word onset. However, the response exclusion account maintains that semantic interference arises after phonological encoding, which is assumed to be accomplished only around 500 ms after picture onset (cf. Indefrey & Levelt, 2004; Roelofs, 2007). Moreover, a response can only be excluded after the task is known, which means that response exclusion can by no means take place in parallel with the task-decision process. Consequently, semantic interference arising from response exclusion cannot be absorbed into the slack created by the task-decision process.

Furthermore, we failed to find semantic interference in delayed naming in three experiments after manipulating the time parameters of stimulus presentation (Experiment 1), the presence or absence of task decisions (Experiments 1 and 2), and the proportion of naming and reading trials in the experiment (Experiment 3). Other features, such as the colours used in the experiments and the instructions given to participants, were already

manipulated by Mädebach et al. (2011), but these authors also failed to induce semantic interference in delayed naming.

2.6.1 Role of attention

We assumed that participants suspend the planning of the picture name before word-form encoding because this stage has been shown to require attention (Reynolds & Besner, 2006; Roelofs, 2008a). An alternative explanation for our findings that does not rely on the cognitive slack logic would be that paying attention to the colour of the distractor word to decide which task to perform reduces the effectiveness of that word as a semantic distractor. This explanation is unlikely, however, based on the following. Firstly, evidence from the colour-word Stroop task (Stroop, 1935) suggests that attending to the colour of a word helps the word to be processed (e.g., La Heij *et al.*, 1995; Lamers & Roelofs, 2007). Similarly, attention to an attribute of an object, such as its movement, facilitates processing of the moving object itself (O'Craven *et al.*, 1999). So it seems unlikely that participants are able to attend to the colour of the word only while preventing processing the word itself, thereby diminishing the word's effectiveness. So this alternative explanation cannot account for our findings as attending to the colour of the word would have, if anything, increased the effectiveness of the distractor word. Secondly, Mädebach et al. (2011) reported an experiment very similar to our Experiment 2; however, the task decision was a go/no-go decision: Depending on the colour of the word, participants named the picture or did not respond at all. They found semantic interference in immediate naming in this case, although the effect was smaller than what they obtained using the standard PWI. As the go/no-go decision is presumably easier than the "name the picture/read the word" decision, these findings provide further support for the proposal that it is the cognitive slack in task decisions, rather than divided attention, that causes semantic interference in the RTs to diminish or even disappear.

Based on our account of relative speed of processing, one may hypothesise that relatively slow responses in immediate naming should show semantic interference because lexical selection presumably took longer than the task-decision process in these cases, and hence no slack was available to absorb the semantic effect. And indeed, for Experiment 2, a semantic interference effect of 25 ms seems to be present in the means of the fifth (i.e., slowest) quantile for immediate naming, although a t-test showed that this effect was not significant, $p > .2$. The prediction of semantic interference for the slowest responses is, however, not as straightforward as it may seem. It is difficult to pinpoint which processes caused longer RTs. It could be that RTs were long because lexical selection took relatively much time, exceeding task-decision duration and prolonging the RTs. If so, there would be no slack and the relatively long RTs should show semantic interference. However, it is equally plausible that the task decision took relatively long, thereby yielding long picture naming RTs. If so, there should be enough slack to absorb the semantic effect, which should then be absent in the relatively slow responses. Moreover, task-decision and lexical selection processes occur early in the chain of processes leading to articulation.

The RTs not only reflect these early processes but also later processes, such as word-form encoding. A relatively long RT could also be the result of the duration of these later processes. Again, RTs would be relatively long, but slack would be present to absorb the semantic interference. In short, it is difficult to directly relate RTs to the duration of each of the different processes. The prediction of semantic interference for the slow responses would only hold if the long RTs are mainly caused by slow picture naming processes up to lexical selection, but this is unlikely to be the case. This reinforces the idea that it is not the variable relative speed of each process that matters but the average relative speed of picture naming and task-decision processes. This is illustrated by the results of computer simulations, which we report next.

2.6.2 Computer simulations of the effect of task decisions

The experiments in the present study support our theoretical claim that task decisions may hide semantic effects from distractor words in picture naming. In this section, we demonstrate the utility of this theoretical account by means of computer simulations using the WEAVER++ model of attention and language performance (e.g., Roelofs, 2003, 2007, 2008a). This model has been applied to divided-attention situations, such as dual-task performance in PRP experiments (Roelofs, 2008a). Besner and Care (2003) pointed out the similarity between task-choice and PRP experiments: Task decisions as well as actual responding in PRP experiments may create cognitive slack, which can hide effects in concurrent tasks. Along the same line, Dell'Acqua et al. (2007) argued that cognitive slack in PRP experiments may absorb semantic interference. Below, we demonstrate that our theoretical account not only explains the effect of task decisions in the present experiments but also the findings of Dell'Acqua et al. (2007) using the PRP procedure. Moreover, the simulations demonstrate that cognitive slack may hide semantic effects even if lexical selection latencies are variable.

The computational protocol was the same as in previous WEAVER++ simulations of picture naming in the PWI paradigm (i.e., Roelofs, 1992, 2003, 2006, 2008a,c). The parameter values were fixed and identical to those in earlier simulations except that the selection threshold was set at 3.0. In the simulations of the effect of task decision in the present experiments, we assumed a task-decision delay of 200 ms after colour perception. These parameter values were informally chosen to optimise the fit between model and data.

The left-hand panel of Figure 2.7 shows the simulation results. Without task decision, a full-blown semantic interference effect occurs in the model, as typically observed with immediate naming in picture-word interference experiments and in the present Experiment 1. However, when a task decision has to be made, cognitive slack may hide the semantic interference in the model, as observed in the present Experiment 2. The semantic effect disappeared in the model even with random lexical selection latencies with a range of 100 ms. Note that, under the assumption of a post-lexical selection suspension point for the picture-word task, semantic interference will only be hidden if task decisions

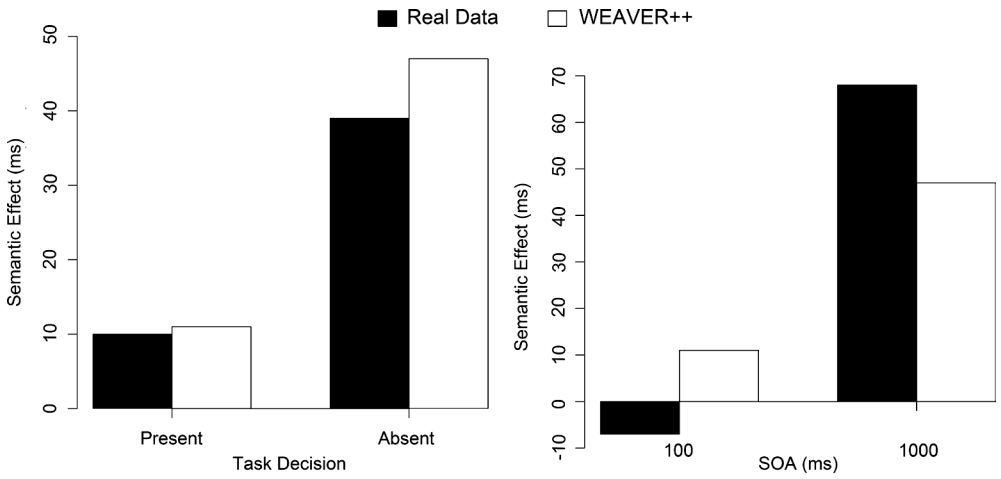

Figure 2.7: Difference in mean naming time for semantically related and unrelated distractor words: Real data and WEAVER++ simulation results. Left-hand panel: The effect of task decision (present in Experiment 2 and absent in Experiment 1). Right-hand panel: The effect of stimulus-onset asynchrony (SOA) in the psychological refractory-period procedure (Dell'Acqua *et al.*, 2007).

take longer than the duration of processes up to and including lexical selection in the semantically related condition, as illustrated in Figure 2.1. In contrast, if task decisions take less time than the processes up to and including lexical selection (not shown in Figure 2.7), semantic interference will be obtained even when a task decision has to be made, which corresponds to what Janssen et al. (2008) empirically observed. As already noted, the difference between the semantically related and unrelated conditions that needs to be absorbed into the slack is small (30-40 ms). This means that slight differences in the duration of task-decision and picture naming processes are already enough to render the semantic effect measurable or not. This is indeed the case in the model. If the task-decision process had been, on average, 25 ms faster than was assumed in the simulations discussed above, a semantic interference effect of 32 ms occurs in the model (not shown in Figure 2.7), which corresponds to what Janssen et al. (2008) observed.

The right-hand panel of Figure 2.7 shows the simulation results for the PRP experiment of Dell'Acqua et al. (2007). Their participants had to indicate the height of a tone (low, medium, high) as the first task and name the picture of picture-word interference stimuli as the second task. The distractor words were semantically related or unrelated. We informally chose a tone-discrimination delay of 300 ms to optimise the fit between model and data. At an SOA of 1,000 ms between the tone and the picture-word stimulus, there is sufficient time for the manual response to the tone to be completed before the onset of the picture-word stimulus. Consequently, cognitive slack is absent in the model and a full-blown semantic interference effect is obtained. However, at an

SOA of 100 ms, manual responding creates cognitive slack, which reduces the semantic interference effect in the model. Thus, semantic interference and SOA are underadditive in the model, which corresponds to what Dell'Acqua et al. (2007) empirically observed.

To conclude, the simulation results demonstrate the utility of our theoretical claim that task decision creates cognitive slack and may, thereby, hide semantic interference, explaining the results of the present Experiments 1 and 2. Moreover, the simulations demonstrate that with slightly faster task decisions, semantic interference is revealed, corresponding to what Janssen et al. (2008) observed. In addition, the simulations demonstrate that manual responding may also create cognitive slack and absorb semantic interference in a PRP experiment. Taken together, the simulation results support a unified account of task decision and PRP effects, in line with what Besner and Care (2003) proposed.

2.7 Summary and Conclusions

In three experiments, we examined the influence of task decisions on semantic effects in immediate picture naming and the replicability of semantic interference effects in delayed naming. We argued that task decisions may hide or reveal semantic effects in immediate naming depending on the relative speed of task-decision and picture-word processing. In support of this account, we obtained semantic interference in immediate naming in a single-task situation requiring picture naming only. By contrast, no semantic effect in immediate naming was obtained using the task-decision design of Janssen et al. (2008). Finally, no semantic interference was found in delayed naming regardless of the materials, of the proportion of reading and naming trials, and of the presence of task decisions. These results support our task-decision account and provide further evidence for competition in lexical selection.

CHAPTER 3

Distractor Strength and Selective Attention in Picture Naming Performance

Whereas it has long been assumed that competition plays a role in lexical selection in word production (e.g., Levelt, Roelofs, & Meyer, 1999), recently Finkbeiner and Caramazza (2006) argued against the competition assumption based on their observation that visible distractors yield semantic interference in picture naming, whereas masked distractors yield semantic facilitation. We examined an alternative account of these findings that preserves the competition assumption. According to this account, the interference and facilitation effects of distractor words reflect whether or not distractors are strong enough to exceed a threshold for entering the competition process. We report two experiments in which distractor strength was manipulated by means of co-activation and visibility. Naming performance was assessed in terms of mean response time (RT) and RT distributions. In Experiment 1, with low co-activation, semantic facilitation was obtained from clearly visible distractors, whereas poorly visible distractors yielded no semantic effect. In Experiment 2, with high co-activation, semantic interference was obtained from both clearly and poorly visible distractors. These findings support the competition-threshold account of the polarity of semantic effects in naming.

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3.1 Introduction

Humans have an amazing capability of quickly selecting words they want to produce out of an immense mental dictionary. A debated topic in the literature concerns how we do this. In other words, what are the mechanisms subserving lexical selection? For a long time, competition was accepted as a mechanism involved in this selection (Levelt *et al.*, 1999; Roelofs, 1992; Starreveld & La Heij, 1996). More recently, however, Finkbeiner and Caramazza (2006b) reported findings challenging this view, and they presented an account of lexical selection without competition, one based on response exclusion. In this article, we first briefly describe the two opposing accounts. Next, we give a brief, critical summary of the evidence in favour of response exclusion, and we argue that the evidence is, in fact, compatible with the competition view. We then propose an alternative account of the findings of Finkbeiner and Caramazza (2006b) that preserves the competition assumption, and present the results of two new experiments supporting this alternative account of the findings.

Over the years, researchers have found effects from context words on picture naming latencies using the picture-word interference (PWI) paradigm. In this paradigm, participants have to name a picture (e.g., the picture of a cat) while trying to ignore a distractor word either superimposed onto the picture (Glaser & Düngelhoff, 1984; Rosinski, 1977) or presented auditorily (Schriefers *et al.*, 1990). A well-known context effect is semantic interference, manifested in longer response times (RTs) for pictures in the context of a category-coordinate (related) distractor word (e.g., *dog*) relative to a semantically unrelated distractor (e.g., *pen*). This semantic interference effect has typically been interpreted as reflecting the competition between the lexical representations of the target picture name and the distractor (Levelt *et al.*, 1999; Roelofs, 1992). According to this account, semantically related words are linked via a conceptual network. When a conceptual representation is activated, it spreads activation to semantically related words via this network and all the activated words compete for selection. The stronger this competition becomes, the longer it takes to select the word that is eventually produced. This delay in selection is what underlies the semantic interference effect. It should be noted, however, that the PWI paradigm not only taps into word selection but also into selective attention. These attention mechanisms allow the participants to respond to the target picture rather than to the distractor word. Mechanisms of selective attention are an explicit part of some models of PWI task performance (Roelofs, 1992, 2003; Starreveld & La Heij, 1996). For example, the WEAVER++ model favours processing of the target over the distractor by reactively blocking the latter (e.g., Roelofs, 2003).

Recently, an alternative explanation of the semantic interference effect in the PWI paradigm has been proposed, called the response exclusion account. Under this account (Finkbeiner & Caramazza, 2006b; Janssen *et al.*, 2008; Mahon *et al.*, 2007), the observed delay in the context of semantically related words arises at a later stage in word production, when articulatory responses to distractors are removed from an output buffer, close to articulation onset. Importantly, evidence for an output buffer locus of the

semantic interference effect would take away the need for assuming competition during lexical selection.

Three assumptions lie at the core of the response exclusion account. The first one is that people form an articulatory response to a distractor word, and this response then enters the output buffer. The second assumption is that only one response can occupy the output buffer at a time. The response to the distractor will reach the output buffer before the response to the picture. Therefore, in a next step, the response to the distractor needs to be excluded from the buffer and replaced by the picture name. The third assumption holds that the mechanism excluding a response from the buffer is sensitive to semantic information. If the response to the distractor shares semantic features (or other task-relevant properties) with the picture name, the process replacing the distractor by the picture name will be delayed, yielding the semantic interference effect. Note that response exclusion concerns an account of selective attention in PWI task performance, describing how target rather than distractor information gains control over responding. On the response exclusion view, the semantic interference effect is not informative about the processes underlying lexical selection, but the effect is informative about how selective attention operates in the PWI paradigm.

3.1.1 The evidence for response exclusion revisited

A number of findings from the PWI paradigm has been taken as evidence for the response exclusion hypothesis: 1) the distractor-frequency effect (Miozzo & Caramazza, 2003), 2) semantic facilitation from part-whole distractors (Costa *et al.*, 2005), 3) the reverse semantic distance effect (Mahon *et al.*, 2007), 4) distractor effects in delayed naming (Janssen *et al.*, 2008), and 5) semantic facilitation from masked distractors (Finkbeiner & Caramazza, 2006b). Before turning to this last piece of evidence, which is central to the present study, we briefly discuss the other evidence.

The distractor-frequency effect is the finding that high-frequency distractor words produce less interference in picture naming than low-frequency distractors (Miozzo & Caramazza, 2003). According to the response exclusion account, compared with low-frequency distractors, high-frequency distractors enter the buffer more quickly. Therefore they are removed from the buffer earlier, which reduces the interference. In contrast, under the assumption that high-frequency words have a higher resting-level of activation than low-frequency words, one could hypothesise that, under a competitive word selection process, high-frequency distractors should interfere more than low-frequency distractors. The fact that the empirical finding goes in the opposite direction than the apparent prediction from competition models has been taken as evidence against competition in lexical selection.

However, the distractor-frequency effect has received an alternative explanation in the literature, which preserves the assumption of lexical competition (Roelofs *et al.*, 2011b). In a competition model such as WEAVER++ (Roelofs, 1992, 2003), an attentional mechanism ensures that picture naming is favoured over distractor word reading

by reactively blocking the distractor (e.g., Roelofs, 2003). The speed of blocking depends on the speed with which the distractor word is recognised (Roelofs, 2005), and lexical frequency is a factor determining the speed of word recognition (e.g., Balota *et al.*, 2004). Consequently, compared with low-frequency distractors, high-frequency distractors are blocked out more quickly and therefore yield less interference, as empirically observed. Thus, both the response exclusion account and competition models like WEAVER++ provide an explanation of the distractor-frequency effect.

The next piece of evidence concerns the semantic facilitation from part-whole distractors, which is the finding that picture naming RTs are shorter relative to unrelated distractors when the distractor word denotes a constituent part of the pictured object, such as the word *bumper* superimposed on a pictured car (Costa *et al.*, 2005). Because the distractor effect is one of semantic facilitation rather than interference, Costa et al. took their finding as evidence against competition models. However, a possible alternative explanation for the facilitation effect obtained by Costa et al., which preserves the assumption of lexical competition, concerns the nature of the relationship between the pictures and distractors used. Many of the picture-distractor pairs had also strong associative relations, as in the example of *bumper* and *car*. Associates have been shown to induce facilitation relative to unrelated distractors (e.g., Alario *et al.*, 2000; La Heij *et al.*, 1990). Thus, the strong associative relation in many of the picture-distractor pairs used by Costa et al. could have driven the observed facilitation effect. Note that this explanation still has to be tested empirically.

The reverse semantic distance effect refers to the finding of Mahon et al. (2007) that semantically close distractor words (e.g., a picture of a horse with *zebra* as a distractor) produce less interference than semantically far distractors (e.g., *frog* as a distractor) in picture naming. According to competition models, semantically close distractors should compete more than semantically far distractors, contrary to what Mahon et al. observed. However, semantic distance effects in agreement with competition models have been obtained in other studies. Using a semantic blocking paradigm, Vigliocco, Vinson, Damian and Levelt (2002) found that, in line with the competition account, naming in blocks of trials with semantically close pictures was slower than in blocks of trials with semantically far pictures. Moreover, so far, two studies have failed to replicate Mahon et al.'s finding on the semantic distance effect caused by distractor words in picture naming (Abdel Rahman *et al.*, 2010; Lee & de Zubicaray, 2010). The observed pattern in these studies was comparable to Vigliocco et al.'s findings and in agreement with competition models: Semantically close distractors yielded more interference than semantically far distractors. Thus, as long as it is not empirically clarified why these different studies obtain diverging results, theoretical conclusions based on the effect of semantic distance should be considered with caution.

A number of studies have reported distractor word effects in delayed naming. Janssen et al. (2008) observed semantic interference in delayed picture naming, when picture names were selected before distractor word onset. Moreover, Dhooge and Hartsuiker (2011b) observed a distractor-frequency effect in delayed naming. These findings are

contrary to what the competition account predicts. However, in the studies of Janssen et al. (2008) and Dhooge and Hartsuiker (2011b), participants had to decide between naming the picture or reading the word aloud depending on the colour of the distractor word, which may have triggered special processes yielding the delayed effects. Moreover, several studies could not replicate the semantic interference effect in delayed picture naming (Mädebach *et al.*, 2011; Chapter 2 of this dissertation). Semantic interference was present in immediate naming throughout the RT distribution, whereas the effect was absent throughout the RT distribution in delayed naming. Again, as long as it is not empirically clarified why these different studies obtain diverging results, theoretical conclusions based on findings from delayed naming should be considered with caution. Further critical analyses of the response exclusion account can be found in La Heij et al. (2006) and Mulatti and Coltheart (2012).

The evidence that is central to the present article comes from a study by Finkbeiner and Caramazza (2006b). These authors manipulated the visibility of the distractor word in a picture naming task. When the distractor is masked, they argued, participants cannot detect it consciously and, thus, no articulatory response to the distractor will be formed. With the output buffer being unoccupied, no response needs to be excluded from the buffer. As a consequence, related distractors should yield facilitation since the masked distractor will not compete with the picture name, but rather prime it via the conceptual-lexical network. This is indeed what Finkbeiner and Caramazza (2006b) observed. Under masked conditions, related distractors facilitated picture naming relative to unrelated distractors. By contrast, when the distractor was not masked, the same set of picture-distractor pairs yielded semantic interference. According to Finkbeiner and Caramazza (2006b), the competition account never predicts semantic facilitation from related distractors (neither under masked nor under visible conditions) since the related distractor should always increase the competition with the picture name. A similar argument is put forward in a recent article that reported a replication of semantic facilitation from masked distractors (Dhooge & Hartsuiker, 2010).

One should note, however, that the facilitation effect elicited by semantically related masked distractors is not in disagreement with the competition hypothesis (see, e.g., Abdel Rahman & Melinger, 2009b; Roelofs, 1992, 1993, 2006, 2008c). Rather, if distractors do not enter in competition with the picture name for selection, they facilitate lexical selection (e.g., Roelofs, 1992, 1993, 2006, 2008c). In what follows, we argue that the findings of Finkbeiner and Caramazza (2006b) may be explained by adopting the assumption of a competition threshold.

3.2 The Competition Threshold Hypothesis

As pointed out above, Finkbeiner and Caramazza (2006b) and Dhooge and Hartsuiker (2010) account for the semantic facilitation effect from masked distractors in terms of the response exclusion hypothesis. When the distractor is not consciously perceived, no

articulatory response will be formed and, thus, the distractor will not enter the output buffer.

In the present article, we examine an alternative explanation for the effects obtained with the masking procedure, the competition threshold hypothesis. This hypothesis does not rely on the assumption of unconscious perception of masked distractors and assumes lexical selection by competition. Under the competition threshold hypothesis, distractor words enter the competition for selection only if they exceed a certain level of activation. Under this view, the net effect of semantically related distractors is one of interference if the distractors enter the competition, but may be one of facilitation if distractors do not compete for selection (see also Abdel Rahman & Melinger, 2009b, for an account in terms of a trade-off between semantic facilitation induced by the context and lexical competition).

According to the competition threshold hypothesis, distractors only become competitors if they receive enough activation to exceed the competition threshold. The function of such a threshold is to operate as an attentional filter (e.g., Broadbent, 1958, 1970, 1971; Broadbent & Gregory, 1964), determining which elements will enter the competition space for response selection. Spreading activation is a powerful and efficient mechanism, making candidates available in parallel, thus enabling a speaker to have a range of candidates quickly available (see Roelofs, 2003, 2008c, for discussion). However, competition is also a costly mechanism in that it increases the metabolic demands of the brain (e.g., Kan & Thompson-Schill, 2004; Schnur *et al.*, 2009) and it may make the selection of the target response difficult. So, it is more beneficial if only the most plausible candidates enter the competition, and these candidates are those with a reasonably strong activation. Different factors can have an influence on the activation strength of the distractor word. In the present study, we investigate the influence of co-activation and of visibility of the distractor. In the following, we describe these two factors in more detail.

It has been shown that masking a word results in a reduction of the evoked neural activity relative to the activity evoked by visible words (Dehaene *et al.*, 2001). Dehaene and colleagues demonstrated that visible words activated a network of brain areas associated with word reading (cf. Fiez & Petersen, 1998), such as left fusiform gyrus, left parietal cortex, and anterior cingulate cortex, among others. Masked words, however, evoked activity only in the left precentral sulcus and in the left fusiform gyrus, an area associated with visual word-forms (cf. Cohen *et al.*, 2000), but did not evoke activation of the anterior cingulate. Crucially, the anterior cingulate cortex is a brain area commonly found to be activated in interference tasks such as the Stroop and the PWI tasks (for a review, see Roelofs, 2008b). This area is assumed to be sensitive to the competition induced by interference tasks. Based on these neuroimaging findings, we assume that masking reduces the input strength of the distractor word. Consequently, masked distractors are less likely to exceed the competition threshold than unmasked distractors. Note that from this perspective, it is not relevant whether the distractor words are consciously perceived or not. What matters for our hypothesis is whether the distractor's activation exceeds the competition threshold, and this may depend on the

distractor's visibility. So even when masking the distractor does not prevent conscious stimulus perception, decreasing the distractors' visibility may be sufficient to reduce its input strength below the competition threshold. Since unconscious perception of the distractor does not play a role in our hypothesis, we use the term 'poorly visible' to refer to distractors that were presented with a masking procedure, and 'clearly visible' to refer to distractors that were not.

The activation strength of a distractor word can also be influenced by the amount of activation it receives from other nodes in the conceptual-lexical network, a factor we refer to as co-activation (see also Abdel Rahman & Melinger, 2009b, for a similar proposal). We manipulated co-activation in two different ways. First, we manipulated response-set membership. Response set refers to the set of items that are correct responses in the experiment (Broadbent, 1970, 1971; Broadbent & Gregory, 1964). The importance of response-set membership in interference tasks has been shown for the Stroop task (Klein, 1964; Lamers *et al.*, 2010) but it is still debated for the PWI task (Caramazza & Costa, 2000, 2001; Roelofs, 2001). In the Stroop task, colour words that function as responses in the experiment produce more interference than colour words that are not part of the response set (Klein, 1964). The effect of response-set membership has been shown to arise due to selective allocation of attention to allowed responses in the experiment (Lamers *et al.*, 2010), for example, through increasing the base-level activation of response-set words (e.g., Cohen *et al.*, 1990). When we apply this view to the PWI task, this implies that using picture names as distractor words will lead to a higher base-level activation of these distractor words. Thus on a given trial, the distractor word is more likely to exceed the competition threshold and to enter the lexical competition. Moreover, by having the distractors as members of the response set in an experiment, the activation of semantically related items is also increased.

Second, we manipulated co-activation by manipulating the number of target pictures belonging to the same semantic category. In one case, pictures of four different exemplars of each category occurred in the experiment (e.g., pictures of four different animals). In the other case, only one picture of each semantic category occurred in the experiment. We assume that in the former case, the different exemplars of the same category will prime each other. Thus, when one exemplar of a given semantic category is presented as distractor while naming another exemplar of this category, the chance that the distractor exceeds the competition threshold should increase. In summary, co-activation may be a powerful factor influencing the strength of the distractor (cf. Roelofs, 2001). If distractors are highly co-activated, they are more likely to exceed the competition threshold than distractors with low co-activation.

To conclude, we hypothesise that distractors only compete with the picture name for selection if their activation exceeds a competition threshold. If they stay below this threshold, they may facilitate lexical selection because they boost the activation of the picture name through spreading activation via the conceptual network (Roelofs, 2008d). We introduced two factors that may affect whether a distractor's activation exceeds this threshold: distractor visibility and co-activation.

In Experiment 1, we tested the prediction that, in the absence of high co-activation, both poorly and clearly visible distractors may lack input strength to exceed the competition threshold. If so, both poorly and clearly visible distractors may yield facilitation due to spreading activation via the conceptual network. Alternatively, the combination of low co-activation and poor visibility may make distractor activation so weak that it not only stays below the competition threshold, but it also does not prime the picture name to a measurable degree. Clearly visible distractors with low co-activation, in turn, may remain below the competition threshold, but the distractor may be activated strongly enough to prime the picture name to a measurable degree. In Experiment 2, we "switched on" co-activation and again compared the effect of distractor visibility. Although masking may decrease the input strength of distractors, once co-activation is high, poorly visible distractors may exceed the competition threshold and yield interference. Moreover, the distractor strength of clearly visible distractors should exceed the competition threshold with high co-activation and thus yield interference.

3.3 Experiment 1

Experiment 1 assessed the effect of distractor visibility with low co-activation. The experiment was very similar to Finkbeiner and Caramazza's (2006b) Experiment 2 although the structure of the trials was slightly modified. Finkbeiner and Caramazza presented the picture in the masked condition with the backward mask superimposed on the picture. The pictures in the visible condition, however, appeared unobstructed, thereby creating a difference in the visibility of the distractors *and* of the pictures between the masked and the visible conditions. We opted for presenting the picture unobstructed in both visibility conditions, keeping the trials in both poorly and clearly visible conditions as similar as possible. Furthermore, all stimuli were always presented in the centre of the screen.

3.3.1 Method

Participants. Eighteen native speakers of Dutch (5 male) from the participant pool of Radboud University Nijmegen participated in the experiment. They received 5 Euros for their participation. All participants had normal or corrected-to-normal vision.

Materials and design. Sixteen pictures of common objects were selected from the picture gallery of the Max Planck Institute for Psycholinguistics, Nijmegen, together with their Dutch basic-level names. Each picture belonged to a different semantic category. The pictures were white line drawings on a black background; the images' size on the screen was approximately 3.5 cm x 3.5 cm. For the related condition, each target picture was paired with a category-coordinate distractor word. The unrelated distractor words were determined by re-pairing each picture name with a different distractor. The semantic relation of the distractor with the picture forms our first independent variable, which we call *distractor type*. In total, there were 32 picture-distractor pairs and the distractor

words were not members of the response set. A list of the materials can be found in Appendix A.3. Backward masks were created for each picture-distractor pair. These consisted of randomly generated consonant strings, such that the consonants used for each pair did not occur in either the name of the picture or in the distractor word. The distractor words and the backward masks were presented in fixed-width font Courier New size 36, colour white. The materials were presented in both poorly and clearly visible conditions, forming our second independent variable, *distractor visibility*. The 32 picture-word pairs were presented four times in each visibility condition. The randomisation of the materials was blocked per repetition such that a given pair could only appear again after all pairs had been presented before. The randomisations were generated using Mix (van Casteren & Davis, 2006) with the following constraints: a) one distractor type condition did not appear on more than three consecutive trials and b) whether a certain picture would first appear in the semantically related or unrelated condition was counterbalanced across participants. The independent variables were manipulated within-participants and within-items. One unique list was used per participant for each visibility condition, totalling 256 trials. Distractor visibility was blocked and all participants took part in the poorly visible condition first followed by the clearly visible condition.

Procedure and apparatus. Participants were seated comfortably in front of a computer monitor, approximately 50 cm away from it. The presentation of stimuli and the recording of responses were controlled by Presentation Software (Neurobehavioral Systems). Stimuli were presented on a 17 in. monitor, using a resolution of 1280 x 1024 and a refresh rate of 75 Hz. Vocal responses were measured with a voice key.

Before the experiment, participants were presented with a booklet to get familiarised with the experimental pictures and their names. They were instructed to name the pictures that would appear on the screen and to ignore what preceded the picture. Next, a block of 16 practice trials was administered. In this practice block, the 16 pictures from the experimental materials were presented once, with a trial structure identical to the trials in the poorly visible condition, except that the masked stimulus, between the forward and the backward masks, was a series of four Xs. Participants named each picture once and were corrected in case the wrong name was used. Next, the poorly visible block was administered followed by the clearly visible block. A trial in the poorly visible block began with a forward mask (##########) presented for 507 ms. The forward mask was immediately replaced by the distractor word, displayed in lower case.[1] The distractor remained on the screen for 53 ms. Next, the backward mask was presented for 13 ms immediately followed by the picture. The picture remained unobstructed on the screen for approximately 800 ms. An empty screen was displayed for the remaining 1700 ms until the next trial started.

In the clearly visible condition, each trial began with a fixation cross presented

[1] In the clearly visible condition, distractors were presented in uppercase. In presenting poorly visible distractors in lowercase and clearly visible distractors in uppercase, we followed the original procedure of Finkbeiner and Caramazza (2006b).

on the centre of the screen for 507 ms. The distractor word, displayed in uppercase letters, replaced the fixation cross and remained on the screen for 53 ms. Next, a blank screen was presented for 13 ms immediately followed by the unobstructed presentation of the picture. The picture remained on the screen for approximately 800 ms, followed by a blank screen for the remaining 1700 ms of the trial. An example of the trial structures is shown in Figure 3.1. The registration of the vocal responses started as soon as the picture was displayed on the screen and lasted 2.5 s. After the experiment proper, participants were asked what they thought they had seen between the hash symbols and the picture during the poorly visible condition. None of the participants reported seeing any Dutch words.

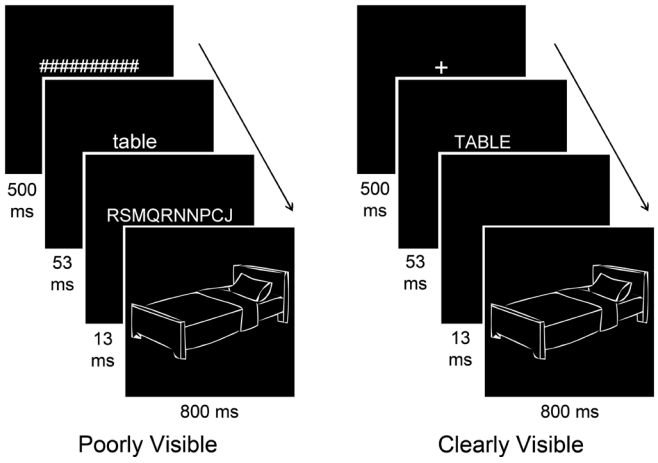

Figure 3.1: Example of the structure of a poorly and a clearly visible trial in Experiments 1 and 2.

Analysis. At each trial, the experimenter evaluated the participants' vocal responses. Trials in which the voice key was triggered by a sound which was not the participant's response and naming RTs shorter than 100 ms were discarded and not included in the error percentages. Responses which contained a disfluency, a wrong pronunciation of the word or a wrong response word were coded as errors and subsequently excluded from the statistical analyses of the naming RTs. We submitted RTs to by-participant (F_1) and by-item (F_2) analyses of variance with distractor type (related and unrelated) and distractor visibility (poorly and clearly visible) as factors. Errors were submitted to logistic regression analysis.

3.3.2 Results

Table 3.1 shows the mean RTs, the standard deviations, and the mean error percentages for poorly and clearly visible distractors. The error analyses revealed that no factor was a

significant predictor in the logistic regression model, all $ps > .100$. Pictures were named on average 8 ms faster in the related condition than in the unrelated condition, $F_1(1,17) = 6.63$, $MSE = 757$, $p = .019$, $F_2(1,15) = 9.64$, $MSE = 443$, $p = .007$. Pictures were named 8 ms faster in the poorly visible condition than in the clearly visible condition, although the effect was only significant in the by-item analysis, $F_1(1,17) = 1.13$, $MSE = 3934$, $p = .301$, $F_2(1,15) = 5.07$, $MSE = 662$, $p = .039$. Distractor type and distractor visibility interacted, $F_1(1,17) = 7.88$, $MSE = 436$, $p = .012$, $F_2(1,15) = 4.69$, $MSE = 630$, $p = .047$. No semantic effect was obtained in the poorly visible condition, $Fs < 1$; but semantic facilitation was present in the clearly visible condition, $F_1(1,17) = 23.47$, $MSE = 357$, $p < .001$, $F_2(1,15) = 13.20$, $MSE = 543$, $p = .002$.

Table 3.1: Mean response time (M), standard deviation (SD), and percent error (PE) as a function of distractor visibility and distractor type in Experiment 1. Mean response times and standard deviations are given in milliseconds.

	Distractor Visibility					
	Poorly Visible			Clearly Visible		
Distractor Type	*M*	*SD*	PE	*M*	*SD*	PE
Related	662	122	1.6	663	136	1.3
Unrelated	664	125	1.7	678	146	2.2
Difference	-2		-.1	-15		-.9

3.3.3 Discussion

Experiment 1 was designed to investigate the role of distractor visibility. As argued, poor visibility of the distractor was assumed to decrease its input strength. We hypothesised that, with low co-activation, poorly visible distractors might yield facilitation or fail to induce semantic context effects. The latter is what we found: Naming was equally fast for related and unrelated poorly visible distractors. Moreover, we hypothesised that clearly visible distractors might have enough activation to induce context effects in picture naming. With low co-activation, clearly visible distractors showed semantic facilitation rather than interference. The facilitation suggests that the distractors failed to exceed the competition threshold, and thus did not enter the competition process. However, their activation still induced a semantic context effect (in this case a facilitation effect) due to priming via the conceptual level.

In basic-level picture naming, it is unusual that category-coordinate distractors facilitate picture naming relative to unrelated distractors (e.g., Roelofs, 1992). Semantic facilitation is obtained, for example, in the case of picture categorisation (e.g., Glaser & Düngelhoff, 1984; Kuipers *et al.*, 2006) or in certain word translation tasks (e.g., La Heij *et al.*, 1996). However, the conditions under which we find semantic facilitation in the present experiment, in particular low co-activation and brief distractor pre-exposure, are only rarely used in PWI studies. Roelofs (1992, 1993) found semantic facilitation from

related distractors with low co-activation when the distractors were presented 100 ms preceding the picture, but not when they were presented simultaneously with the picture, in which case no semantic effects were obtained. So both in Roelofs (1992, 1993) and in the present experiment, there was low co-activation and the distractor preceded the picture. This appears to be sufficient to decrease the input strength of the distractor below the competition threshold. By contrast, when distractors are presented under conditions of high co-activation, which is the case in most PWI studies (e.g., Glaser & Düngelhoff, 1984), or presented simultaneously with the picture under low co-activation for a longer period (e.g., 600 ms, Caramazza & Costa, 2000), the input strength of the distractors exceeds the competition threshold. Thus it appears that the finding of semantic facilitation in basic-level naming in the present experiment is related to the use of specific experimental parameters decreasing the distractor's input strength.

To sum up, with low co-activation, we found no effect of distractor type on the RTs in picture naming with poorly visible distractors, whereas semantic facilitation was observed with clearly visible distractors. These results are in accordance with the competition threshold hypothesis.

3.4 Experiment 2

Experiment 2 was designed to investigate to what extent co-activation contributes to distractor strength. The experiment was nearly identical to Experiment 1, except that we increased, in two ways, the amount of co-activation that pictures and distractors could induce. First, there were four exemplars of each semantic category (e.g., pictures of four different animals) rather than just one exemplar of each category as was the case in Experiment 1. Second, the distractors used in the experiment were the names of other pictures that appeared in the experiment. This should increase the base-level activation of distractors throughout the experiment and thus increase the chance that a distractor's activation exceeds the competition threshold. These manipulations combined should increase the amount of activation a distractor will receive from other activated lexical nodes (see also Abdel Rahman & Melinger, 2009b).

If co-activation is an important factor in determining distractor strength, it will increase the chance that distractors exceed the competition threshold, and consequently, interfere with picture naming. If the increase of distractor activation by the presence of co-activation is strong enough to activate the distractor beyond the competition threshold, we should observe semantic interference with poorly and clearly visible distractors. It could, however, also be the case that the competition threshold is only exceeded by clearly visible distractors, whereas poorly visible distractors stay below the threshold but are activated strongly enough to prime the picture name. In that case, we should observe interference from clearly visible distractors and facilitation from poorly visible distractors, as Finkbeiner and Caramazza (2006b) and Dhooge and Hartsuiker (2010) obtained.

3.4.1 Method

Participants. Sixteen young adults (2 male) participated in the experiment and received a reward of 5 Euros for their participation. They were from the same participant pool as in Experiment 1 and they met the same eligibility requirements.

Materials and design. Thirty-two pictures of common objects were selected from the same picture gallery as for Experiment 1. The objects belonged to eight different semantic categories with four objects per semantic category. Each target picture was paired with a semantically related distractor, and the semantically unrelated distractors were created by re-pairing the pictures with different distractors, yielding 64 picture-distractor pairs. All distractors belonged to the response set. A list of the materials can be found in Appendix A.4. Backward masks were created for each picture-distractor pair in the same way as in Experiment 1. The design was identical to Experiment 1. One unique list was used per participant with a total of 512 experimental trials.

Procedure, apparatus, and analysis. The procedure and apparatus were identical to Experiment 1. For Experiment 2, the familiarisation block consisted of the 32 pictures used as experimental materials. For the debriefing, none of the participants reported seeing any Dutch words in the poorly visible condition. The same analyses were conducted as for Experiment 1.

3.4.2 Results

Table 3.2 shows the mean RTs, the standard deviations, and the mean error percentages for poorly and clearly visible distractors. The error analyses revealed that no factor was a significant predictor in the logistic regression model, all ps $> .200$. Pictures were named on average 10 ms faster in the poorly visible than in the clearly visible condition, $F_1(1,15) < 1$, $F_2(1,31) = 5.68$, $MSE = 1863$, $p = .023$, and 14 ms slower in the related condition than in the unrelated condition (i.e., a semantic interference effect), $F_1(1,15) = 12.02$; $MSE = 1156$; $p = .003$, $F_2(1,31) = 4.57$, $MSE = 6722$, $p = .041$. The interaction between visibility and distractor type was not significant, Fs < 1.

3.4.3 Discussion

The aim of Experiment 2 was to investigate the role of co-activation in determining the input strength of the distractor word. Co-activation was manipulated in terms of response-set membership and by increasing the number of exemplars from the semantic categories used in the experiment. We obtained semantic interference in picture naming from both poorly and clearly visible distractors and the semantic interference effect did not differ between the two visibility conditions in the mean RTs. These findings are in agreement with the competition threshold hypothesis. Moreover, they point to the importance of co-activation and response-set membership in the PWI task (cf. Roelofs, 2001).

Table 3.2: Mean response time (M), standard deviation (SD), and percent error (PE) as a function of distractor visibility and distractor type in Experiment 2. Mean response times and standard deviations are given in milliseconds.

	Distractor Visibility					
	Poorly Visible			Clearly Visible		
Distractor Type	*M*	*SD*	PE	*M*	*SD*	PE
Related	714	181	2.3	721	198	1.8
Unrelated	697	168	1.6	708	176	1.4
Difference	17		0.7	13		0.4

Note that the response exclusion hypothesis can explain the results of Experiment 2 without any extra assumptions. The fact that distractors are also used as targets, i.e., they are part of the response set, makes them very response relevant, which is a factor determining the speed with which the output buffer can be emptied. However, the account cannot explain the results of Experiment 1. In Experiment 1, the distractors are not part of the response set. In the clearly visible condition, an articulatory response is derived for the distractors, which would predict semantic interference, rather than semantic facilitation, which is what we observed.

3.4.4 Analyses of RT distributions

Whereas Finkbeiner and Caramazza (2006b) obtained semantic facilitation from masked distractors, we obtained no effect in Experiment 1 and semantic interference in Experiment 2. Proponents of the response exclusion hypothesis could argue that the null effect in Experiment 1 and the semantic interference in Experiment 2 are due to differences in conscious perception of the distractors across the poorly visible trials. It could be that on a proportion of the trials, the poorly visible distractors were perceived consciously. From a response-exclusion point of view, they should enter the response buffer and yield semantic interference. At the same time, on another proportion of the trials, masking may have been effective, preventing an articulatory response to the distractor to enter the buffer, which should yield facilitation. The null effect in the mean RTs of Experiment 1 could reflect the net result of a mixture of trials with interference and facilitation. In fact, such null effects in the mean RTs, resulting from different opposing underlying effects, have been reported in the Stroop literature (e.g., Heathcote *et al.*, 1991). Similarly, the interference from poorly visible distractors in Experiment 2 could reflect that there was a larger proportion of trials with interference and a smaller proportion of trials with facilitation. On this account, conscious perception of the distractor words would be crucial, but the experiments were unsuccessful in preventing conscious perception on all poorly visible trials.

One way to address the possibility of a mixture of effects is by conducting RT distributional analyses. We performed both Vincentile and ex-Gaussian analyses.

In Vincentile analyses, group RT distributions are examined (see Ratcliff, 1979). For these analyses, we rank-ordered the RTs for each participant and then divided them into 20% quantiles. We then computed quantile means for each condition and finally averaged the quantiles across participants. Ex-Gaussian analyses formally characterise an RT distribution by fitting an ex-Gaussian function to the RT data, which consists of a convolution of a Gaussian and an exponential function. The analysis provides three parameters characterising a distribution: μ, reflecting the mean of the Gaussian portion; σ, reflecting the standard deviation of the Gaussian portion; and τ, reflecting the mean and standard deviation of the exponential portion (e.g., Heathcote *et al.*, 1991; Luce, 1986; Ratcliff, 1979). Theoretically, the mean of the whole distribution equals the sum of μ and τ. Thus, ex-Gaussian analyses decompose mean RTs into two additive components, which characterise the leading edge (μ) and the tail (τ) of the underlying RT distribution.

Mean RTs are generally shorter in masked than in visible conditions (e.g., Dhooge & Hartsuiker, 2010, and the present experiments). For example, Dhooge and Hartsuiker used similar timing parameters for their masked and visible conditions, only altering the presence or absence of the backward mask. Moreover, using a visibility test, they showed that their masked distractors were not perceived consciously. RTs in the masked condition were overall shorter than in the visible condition. Given that participants tend to be faster under masked conditions, then the shortest RTs in the distribution should, in general, reflect the trials in which the masking procedure was effective. Similarly, the longest RTs should be more associated with trials in which the masking procedure was ineffective or failed. If the absence of a semantic effect from poorly visible distractors in Experiment 1 is due to a mixture of trials with facilitation and interference effects, then the shortest RTs should show facilitation, whereas the longest RTs should show interference. This situation predicts a cross-over between the RT curves for the related and unrelated conditions in the Vincentiles and opposing effects in the parameters μ and τ, cancelling each other out in the mean RTs. Similarly, if the interference effect from poorly visible distractors in Experiment 2 is due to a large number of trials with interference, then this interference should be especially prominent in the longest RTs, i.e., towards the tail of the distribution, revealing a τ effect.

Figure 3.2 shows the Vincentised cumulative distribution curves for picture naming for the related and unrelated distractors in the two visibility conditions of both experiments. The curves for the related and unrelated poorly visible distractors of Experiment 1 are entirely overlapping, showing that the null effect is not due to a mixture of underlying facilitation and interference effects. The semantic facilitation for clearly visible distractors in Experiment 1 is evidenced as a shift of the entire curve for the unrelated distractors relative to the related distractors, showing that facilitation is present throughout the RT distribution. The semantic interference effect from poorly visible distractors in Experiment 2 is evidenced as a shift of the entire distribution for the related condition relative to the unrelated condition, whereas the interference effect from clearly visible distractors is especially prominent towards the tail of the distribution. Thus, the

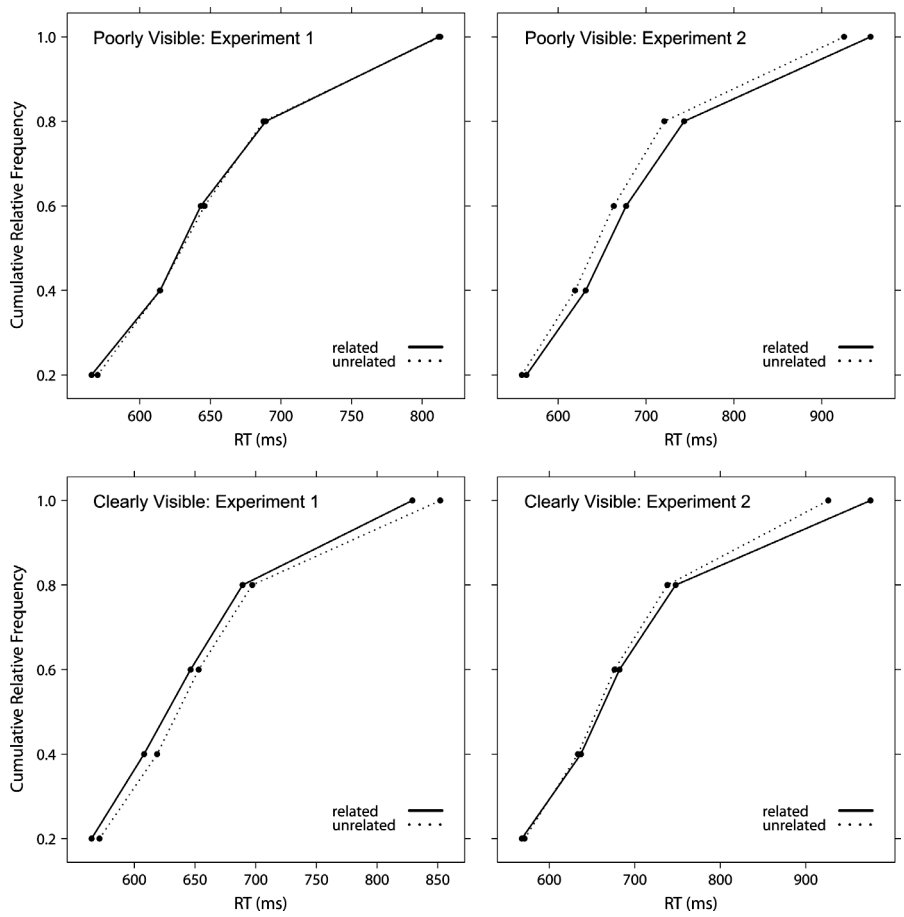

Figure 3.2: Vincentised cumulative distribution curves for picture naming for related and unrelated distractors in the poorly visible (top left panel) and clearly visible (bottom left panel) conditions in Experiment 1 and in the poorly visible (top right panel) and clearly visible (bottom right panel) conditions in Experiment 2. RT = response time.

Vincentile analyses show that the absence of a semantic effect of poorly visible distractors in Experiment 1 and the semantic interference of poorly visible distractors in Experiment 2 are not due to underlying mixtures of interference and facilitation effects across trials.

Table 3.3 shows the means of the ex-Gaussian parameters for poorly and clearly visible distractors of Experiments 1 and 2. In Experiment 1, for the clearly visible condition, two-tailed dependent t-tests revealed a marginally significant semantic facilitation in the μ parameter, $t(17) = $ -1.86, $p = .081$. The remaining comparisons were not significant, all ps $> .124$. Thus, no differences were found in any of the ex-Gaussian parameters for the poorly visible condition, indicating that the RT distributions overlapped. In Exper-

iment 2, dependent t-tests revealed semantic interference in the poorly visible condition in the μ parameter, $t(15) = 2.21$, $p = .043$, indicating that the semantic effect shifted the entire RT distribution. In the clearly visible condition, semantic interference was present both in σ, $t(15) = 2.81$, $p = .013$; and in τ, $t(15) = 2.96$, $p = .009$. Thus, the ex-Gaussian analyses confirm the conclusions of the Vincentile analyses that the absence of a semantic effect of poorly visible distractors in Experiment 1 and the semantic interference of poorly visible distractors in Experiment 2 are not due to underlying mixtures of interference and facilitation effects.

To conclude, the null effect of poorly visible distractors in Experiment 1 is not due to a mixture of underlying facilitation and interference effects, but instead, a semantic effect is absent throughout the whole RT distribution. Moreover, the interference effect of poorly visible distractors in Experiment 2 is not due to a greater number of trials showing interference and a smaller number showing facilitation, but instead is due to interference that is present throughout the RT distribution.

Table 3.3: Mean ex-Gaussian parameter estimates (in milliseconds) as a function of distractor visibility and distractor type in Experiments 1 and 2.

Distractor Visibility		Experiment 1			Experiment 2		
	Distractor type	μ	σ	τ	μ	σ	τ
Poorly Visible							
	Related	579	36	83	581	54	133
	Unrelated	583	36	81	571	49	126
	Difference	-4	0	2	10	5	7
Clearly Visible							
	Related	573	35	90	584	57	138
	Unrelated	581	38	98	587	48	121
	Difference	-8	-3	-8	-3	9	17

3.5 General Discussion

The role of competition in lexical selection is a hotly debated issue. While several models assume competition as a mechanism operating in lexical selection (e.g., Levelt *et al.*, 1999; Roelofs, 1992), recent studies have claimed that the semantic interference effect, previously taken as evidence for competition, should be accounted for as a response-exclusion effect instead (e.g., Dhooge & Hartsuiker, 2010; Finkbeiner & Caramazza, 2006b; but see Mädebach *et al.*, 2011; Roelofs *et al.*, 2011b; and Chapter 2).

Finkbeiner and Caramazza (2006b) observed semantic interference in picture naming with visible distractors, but the semantic effect was one of facilitation when distractors were presented under masked conditions. The response exclusion hypothesis accounts for this finding by assuming that, for masked distractors, no articulatory response

enters the output buffer since masked distractors are not consciously perceived. We proposed an alternative competition account of the semantic effects observed from masked and visible distractors that does not rely on the assumption of unconscious processing of masked distractors: the competition-threshold hypothesis. According to this hypothesis, a threshold determines whether distractors do or do not enter in competition with the picture name for selection. This competition threshold is a mechanism of selective attention, which determines to what extent contextual information is allowed to influence lexical selection. We investigated the role of distractor visibility and co-activation as potential determinants of the input strength of the distractor word, and thus as potential determinants as to whether the distractor does exceed the competition threshold.

In Experiment 1, with low co-activation, poorly visible distractors did not yield semantic effects in picture naming whereas clearly visible distractors yielded semantic facilitation. Thus, different from Finkbeiner and Caramazza's (2006b) findings, semantic facilitation was obtained from clearly visible distractors, which is in agreement with the competition-threshold hypothesis. Experiment 2 was set up such that co-activation was high. Now, both poorly and clearly visible distractors yielded semantic interference in picture naming. Thus, different from Finkbeiner and Caramazza's findings, but in line with the competition-threshold hypothesis, semantic interference was obtained for poorly visible distractors. The competition-threshold hypothesis provides a mechanism of selective attention that accounts for the present results without the need to involve notions such as awareness and formulation of an articulatory response.

We proposed that distractor visibility influences the strength of activation of distractor words. Note that we do not claim that masked words are too weakly activated to elicit any effects. This claim would be ungrounded given a vast literature on masking showing that masked primes are powerful stimuli, capable of eliciting various kinds of effects (e.g., Forster & Davis, 1991; Grainger *et al.*, 2003). Rather, our claim is that decreasing the visibility of a distractor will decrease the likelihood of that distractor to enter in competition with the picture name for selection.

Concerning the effect of co-activation, the question may be asked how our findings relate to previous investigations of response-set membership (Caramazza & Costa, 2000, 2001; Roelofs, 2001). Caramazza and Costa (2000) questioned the role that response-set membership plays in a competitive model such as WEAVER++. They manipulated the materials such that distractors were not members of the response set and only one exemplar of each semantic category was used. This manipulation is very similar to what we used in Experiment 1, which was our experiment with low co-activation. Whereas Costa and Caramazza observed semantic interference from distractors with low co-activation, we obtained semantic facilitation for visible distractors. This may not be a discrepancy, however, given procedural differences between their experiment and our Experiment 1. Our distractors were presented for 53 ms preceding the picture, with an SOA of 66 ms, followed by an unobstructed picture for 800 ms. Costa and Caramazza had the picture and the distractor word presented simultaneously, with the distractor superimposed for 600 ms. Given our findings about the role of distractor visibility on the semantic effect,

the apparent discrepancy is readily explained. In the case of Costa and Caramazza's study, the visibility and salience of the distractor caused it to exceed the competition threshold, despite the lack of distractor strength due to low co-activation.

One finding in the literature that may seem to be in contrast with the account proposed here is the distractor frequency effect (Miozzo & Caramazza, 2003). It could be argued that high-frequency distractors are more likely to cross the competition threshold than low-frequency distractors. If so, high-frequency distractors should yield more interference than low-frequency ones. It should be noted, however, that the competition-threshold hypothesis is concerned with the likelihood that a given distractor will cross the competition threshold. If distractors exceed the threshold, the distractor frequency effect can be accounted for by a distractor blocking mechanism (see Roelofs *et al.*, 2011b), as mentioned in the introduction. Investigations of the distractor frequency effect have made use of clearly visible distractors, presented for at least 700 ms (e.g., Miozzo & Caramazza, 2003), which should be sufficient for both the high- and low-frequency distractors to pass the threshold. Indeed, the size of the semantic interference effect has been shown to be comparable for high- and low-frequency distractors (Miozzo & Caramazza, 2003), suggesting that those distractors passed the competition threshold. Under poorly visible conditions, the distractor frequency effect is absent (Dhooge & Hartsuiker, 2010), in line with the account proposed here. Roelofs et al. (2011b) report the results of computer simulations of the experiments of Dhooge and Hartsuiker (2010) using WEAVER++, which showed the utility of our account of the distractor-frequency effect and the effect of masking.

In addition to analysing mean RTs, we also conducted RT distribution analyses to further examine the findings reflected in the mean RTs. In Experiment 1, we observed that the null effect from poorly visible distractors was not due to a mixture of underlying interference and facilitation effects, possibly emerging from a mixture of trials in which the masking procedure was effective and trials in which it was not. Rather, a semantic effect in the poorly visible condition was absent throughout the entire RT distribution. With high co-activation in Experiment 2, poorly visible semantically related distractors shifted the RT distribution relative to unrelated distractors. Thus, interference was present throughout the RT distribution, suggesting that poorly visible related distractors consistently caused interference across the poorly visible trials, rather than producing interference on a large number of trials (reflecting ineffective masking) and facilitation on fewer trials (reflecting effective masking).

It has become increasingly clear that selective attention plays an important role in performance in the PWI paradigm (see e.g., Roelofs, 2003, 2007, 2008d; Roelofs *et al.*, 2011b). In the selective attention literature, a distinction is made between early selection (input filtering) based on physical or perceptual features, and late selection, operating at the level of response selection. Both types of selection usually play a role in task performance, as suggested by the seminal work of Broadbent and colleagues (Broadbent, 1970, 1971; Broadbent & Gregory, 1964). WEAVER++ implements assumptions about both types of attention. The competition-threshold hypothesis is a concrete proposal for a

late selective attention mechanism, determining which elements will enter the competition space for response selection, whereas our distractor-blocking mechanism (Roelofs *et al.*, 2011b) is an early selection mechanism. By stipulating two loci of selective attention in PWI, we are staying close to the literature on attention, and we are not abandoning parsimony.

3.6 Summary and Conclusion

Finkbeiner and Caramazza (2006b) observed semantic facilitation from masked distractors and semantic interference from visible distractors in picture naming. These findings were taken to refute competition models. In the present article, we proposed an alternative explanation of the findings of Finkbeiner and Caramazza that preserves the assumption of lexical competition. In two experiments, we examined the hypothesis that there is a lexical-competition threshold which determines whether distractors will enter the competition with the picture name for selection. We investigated the role of distractor visibility and co-activation in determining the likelihood of a distractor to exceed the competition threshold. Supporting our hypothesis, we obtained semantic interference under conditions that were predicted to increase the input strength of the distractor word, causing it to surpass the threshold. Moreover, we obtained semantic facilitation under conditions that decreased distractor strength. We argued that the competition-threshold hypothesis is capable of accounting for the polarity of semantic context effects in picture-word interference tasks and that the semantic facilitation from masked distractors does not represent a challenge to lexical selection by competition.

CHAPTER 4

Distinct patterns of brain activity characterise lexical activation and competition in spoken word production

According to a prominent theory of language production, concepts activate multiple associated words in memory, which enter into competition for selection. However, only a few electrophysiological studies have identified brain responses reflecting competition. Here, we report a magnetoencephalography study in which the activation of competing words was manipulated by presenting pictures (e.g., dog) with distractor words. The distractor and picture name were semantically related (*cat*), unrelated (*pin*), or identical (*dog*). Related distractors are stronger competitors to the picture name because they receive additional activation from the picture relative to other distractors. Picture naming times were longer with related than unrelated and identical distractors. Phase-locked and non-phase-locked activity were distinct but temporally related. Phase-locked activity in left temporal cortex, peaking at 400 ms, was larger on unrelated than related and identical trials, suggesting differential activation of alternative words by the picture-word stimuli. Non-phase-locked activity between 400-650 ms (4-10 Hz) in left superior frontal gyrus was larger on related than unrelated and identical trials, suggesting differential resolution of the competition among the alternatives, as reflected in the naming times. These findings characterise distinct patterns of activity associated with lexical activation and competition, supporting the theory that words are selected by competition.

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4.1 Introduction

A core process in spoken language production is the quick and accurate retrieval of intended words from long-term memory. According to a prominent theory (Levelt, 2001; Levelt *et al.*, 1999; Roelofs, 2003; Roelofs & Hagoort, 2002; Roelofs & Piai, 2011), conceptually driven word retrieval involves the activation of a set of candidate words in left middle temporal cortex, and competitive selection of the intended word from this set regulated by frontal cortical mechanisms. However, although competition is widely regarded in the cognitive neurosciences as a ubiquitous mechanism (Desimone & Duncan, 1995; Miller & Cohen, 2001), its role in lexical selection has recently been disputed (Blackford *et al.*, 2012; Finkbeiner & Caramazza, 2006a,b; Oppenheim *et al.*, 2010). Whereas electrophysiological studies have provided evidence for the activation of multiple lexical candidates, no study so far has identified brain responses reflecting the top-down resolution of lexical competition. Here, we provide evidence from magnetoencephalography (MEG) that evoked (i.e., phase-locked) activity in left temporal cortex and induced (i.e., non-phase-locked) activity in superior frontal cortex characterise, respectively, lexical activation and competition in overt picture naming, thereby supporting the theory of lexical selection by competition.

Earlier behavioural evidence for multiple lexical activation and competition comes from studies of picture naming in which the amount of lexical competition is manipulated by simultaneously presenting distractor words. These words may be semantically related (e.g., a picture of a dog combined with the word *cat*), unrelated (pictured dog, word *pin*), or identical (pictured dog, word *dog*) to the picture name. Picture naming response time (RT) is typically longer in the related than in the unrelated condition, referred to as the *semantic* effect, and longer in the related than in the identity condition, referred to as the *Stroop-like* effect (Glaser & Düngelhoff, 1984; Lupker, 1979). According to the theory (Levelt, 2001; Levelt *et al.*, 1999; Roelofs, 2003; Roelofs & Hagoort, 2002; Roelofs & Piai, 2011), a picture (e.g., of a dog) activates, to different degrees, multiple lexical candidates that are semantically related (e.g., dog, cat, goat, etc.). In particular, the picture (e.g., of a dog) will prime the distractor word (e.g., *cat*) via conceptual connections in memory, referred to as *reverse priming* (La Heij *et al.*, 1990; Neumann, 1986), and the distractor word will prime the picture name. Accordingly, a semantically related distractor word (e.g., *cat*) receives further activation from the picture (dog) and is therefore a stronger competitor to the picture name than an unrelated distractor word (e.g., *pin*), which is not activated by the picture. When picture name and distractor are identical (*dog*), activation of the intended word will be increased relative to alternative words. The enhanced activation of the distractor word in the related condition compared with the other conditions prolongs the duration of word selection and yields the semantic and Stroop-like interference effects in the RTs. Thus, the semantic (related vs. unrelated) and Stroop-like (related vs. identity) effects reflect the involvement of competition in lexical selection. The account of lexical selection in terms of activation (reverse priming)

and competition has been implemented in computational models of word production, including the model of Starreveld and La Heij (1996), and WEAVER++ (e.g., Levelt *et al.*, 1999; Roelofs, 1992, 2003; Roelofs & Hagoort, 2002; Roelofs & Piai, 2011; Roelofs *et al.*, 2013), which successfully simulates a wide range of findings in the literature on spoken word production (e.g., Levelt *et al.*, 1999; Roelofs, 1992, 2003).

Previous electrophysiological (EEG) studies examining lexical selection in picture naming have provided evidence for the activation of multiple lexical candidates (Blackford *et al.*, 2012; Dell'Acqua *et al.*, 2010). These studies observed an N400 response, which is a broad negative-going event-related potential (ERP) that usually peaks at approximately 400 ms post-stimulus onset (Kutas & Hillyard, 1980; Kutas & Federmeier, 2011; Lau *et al.*, 2008). Put very generally, the amplitude of the N400 response seems to reflect the ease of integration of or access to stored representations (Kutas & Federmeier, 2011; Lau *et al.*, 2008). In particular, semantically primed stimuli elicit an attenuated N400 response relative to unprimed stimuli (see for review Kutas & Fedemeier, 2011). In picture naming with distractor words, the amplitude of the N400 tends to be larger in the unrelated than in the related and identity conditions, i.e., unrelated > related > identity (Blackford *et al.*, 2012; Dell'Acqua *et al.*, 2010; Greenham *et al.*, 2000, but note that Blackford et al. did not use a conventional picture-word interference paradigm), suggesting the activation of multiple lexical alternatives. The co-activation of semantic alternatives (due to priming) reduces the effort of processing the picture name (dog) and the distractor word (*cat*) in the related condition relative to the unrelated condition (*pin*), where there will be no such co-activation. When picture name and distractor word are identical, their activation converges on a single word in memory (dog), reducing processing effort even further.

However, activation of multiple lexical candidates does not necessarily imply that the selection of the intended word is a competitive process (Blackford *et al.*, 2012; Oppenheim *et al.*, 2010). On an alternative account, picture and word also prime each other in the related condition (Finkbeiner & Caramazza, 2006b). However, candidate words do not enter into competition but rather the first word that exceeds an activation threshold is selected (Finkbeiner & Caramazza, 2006a,b; Janssen *et al.*, 2008). Under this account, the semantic and Stroop-like effects arise when an articulatory programme derived for the distractor word needs to be excluded from an articulatory buffer to give place to the articulatory programme for the picture name (e.g., Dhooge & Hartsuiker, 2010; Finkbeiner & Caramazza, 2006b). The decision mechanism that excludes the programme for the distractor from the buffer is assumed to be sensitive to whether the distractor word belongs to the same semantic category as the picture, explaining the semantic and Stroop-like effects in the RTs.

The ERP findings in the literature may have provided evidence for the co-activation of lexical candidates, but only a few studies have identified increased brain responses that are analogous to the increase in RTs for the related condition compared with the unrelated and identity conditions (Aristei *et al.*, 2011; Costa *et al.*, 2009; Maess *et al.*, 2002). According to Blackford et al. (2012), the finding of an attenuated N400

(related < unrelated ERP amplitudes) associated with increased RTs in the related condition (related > unrelated RTs), as observed in the literature (Blackford *et al.*, 2012; Dell'Acqua *et al.*, 2010; Greenham *et al.*, 2000), challenges the theory that competition is involved in lexical selection (Levelt, 2001; Levelt *et al.*, 1999; Roelofs, 2003; Roelofs & Hagoort, 2002; Roelofs & Piai, 2011).

Importantly, ERPs are calculated by averaging, over several trials, the EEG signal time-locked to a stimulus. This may capture electrophysiological activity that is phase-locked to the stimulus, referred to as *evoked activity*, but will miss brain activity that is not phase-locked to the stimulus, referred to as *induced activity* (Tallon-Baudry & Bertrand, 1999). Induced activity may be examined, though, by means of time-frequency representations (TFRs), which capture changes in oscillatory brain activity over time, regardless of phase locking. Previous research suggests that evoked and induced activity may reflect largely distinct functional processes (Laaksonen *et al.*, 2012; Tallon-Baudry & Bertrand, 1999). In particular, whereas bottom-up processes, like memory activation in the present context, can be reflected in evoked and induced activity, induced activity seems to be more dependent on top-down processes (Chen *et al.*, 2012; Tallon-Baudry & Bertrand, 1999), like executive control over memory representations in the present context. Resolving lexical competition requires top-down executive control over activated lexical candidates (Roelofs, 2003; Roelofs & Hagoort, 2002; Roelofs & Piai, 2011). In short, previous EEG studies reporting an attenuated N400 amplitude associated with the semantic interference effect in RTs may have failed to find evidence for competition because they examined evoked brain activity only.

The present study aimed at an electrophysiological characterisation, both in time and in terms of involved brain areas, of the competition that is triggered by the semantic co-activation of lexical candidates. Participants overtly named pictures, while trying to ignore distractor words that were semantically related (e.g., a picture of a dog combined with the word *cat*), unrelated (*pin*), or identical (*dog*). We used MEG to examine evoked and induced activity associated with distractor effects. Changes in event-related fields (ERFs, the magnetoencephalographic equivalent of ERPs) were expected to reflect the activation of multiple candidates (Blackford *et al.*, 2012). The neuronal generators of the N400 effect in picture-word interference studies are unknown. However, the activation of multiple lexical candidates in picture naming has been associated with left middle temporal gyrus (MTG) (Indefrey, 2011; Indefrey & Levelt, 2004; Levelt, 2001; Levelt *et al.*, 1999). Based on earlier ERP studies, we expected the ERF amplitude in left MTG to be larger in the unrelated than in the related and identity conditions (Blackford *et al.*, 2012; Dell'Acqua *et al.*, 2010; Greenham *et al.*, 2000). The induced activity, in turn, was expected to reflect competition resolution processes. Although very little is known about oscillations in picture naming (Ewald *et al.*, 2012; Laaksonen *et al.*, 2012; Piai *et al.*, 2012b, Chapter 6), power modulations in the theta (4-7 Hz) and alpha (8-12 Hz) frequency bands have been observed in a colour-word Stroop analog of picture-word interference using manual responding (Hanslmayr *et al.*, 2008). Competition effects

in Stroop-like tasks are typically localised to frontal cortex (Aarts *et al.*, 2009), which is also associated with executive control in word production (Roelofs, 2003; Roelofs & Hagoort, 2002; Roelofs & Piai, 2011). Therefore, we expected competition resolution in picture naming to be reflected in induced activity in a frequency band between 4-12 Hz in frontal brain areas. Activity should be larger for the related than unrelated and identity conditions, corresponding to the condition ordering of the mean RTs.

According to the noncompetitive account of word retrieval (Dhooge & Hartsuiker, 2010; Finkbeiner & Caramazza, 2006a,b; Janssen *et al.*, 2008), the interference in the naming RTs arises after word planning, in an articulatory buffer, "at the point of deciding which of two articulatory programs should be excluded from the output buffer in order that the correct response may be produced" (Finkbeiner & Caramazza, 2006a, p. 1033). Importantly, meta-analyses have provided time estimates indicating that an articulatory programme reaches the buffer no earlier than about 145 ms before articulation onset (Indefrey, 2011; Indefrey & Levelt, 2004). We used response-locked analyses to assess whether modulations of induced brain activity happen later than 145 ms before articulation onset, as predicted by the noncompetitive account (Dhooge & Hartsuiker, 2010; Finkbeiner & Caramazza, 2006a,b; Janssen *et al.*, 2008), or earlier in time, as predicted by the lexical competition account (Levelt, 2001; Levelt *et al.*, 1999; Roelofs, 2003; Roelofs & Hagoort, 2002; Roelofs & Piai, 2011). Response-locked analyses have been proposed as a tool to help adjudicate between the two accounts: "Additional methods of analysis, examining [...] backwards from naming onset, will be required to determine whether [...] behavioral semantic interference occur at intermediate stages or at very late stages of processing during preparation of the articulatory response." (Blackford *et al.*, 2012, p. 97).

4.2 Method

Participants

Seventeen healthy right-handed, Dutch adults (6 male) voluntarily participated in the experiment for monetary compensation or for course credits. All participants had normal or corrected-to-normal vision, and no history of neurological or language deficits. Participants gave written consent after they were completely informed about the nature of the study. The experiment was approved by the Ethics Committee for Behavioural Research of the Social Sciences Faculty at Radboud University Nijmegen and followed the Declaration of Helsinki (World Medical Association 1964, 2008).

Materials, design, and behavioural procedure

Thirty-six line drawings of common objects, belonging to nine different semantic categories, were taken from the picture database of the Max Planck Institute for Psycholinguistics, Nijmegen. The materials are listed in Appendix A.5. Each picture was paired with a distractor word. In the identity condition, the distractor was the picture's Dutch basic-level name. For the related condition, picture names from the same semantic cat-

egory were used, and from a different category in the unrelated condition. Thus, our distractor words were part of the response set (compare with Blackford *et al.*, 2012; Greenham *et al.*, 2000; Hirschfeld *et al.*, 2008; Dell'Acqua *et al.*, 2010). All picture-word pairs were presented four times each. Thus, all participants saw all pictures in all conditions, with one unique randomisation per participant. Participants were instructed to name the pictures and to ignore the words. Next, they were familiarised with the pictures and their names. After a short practice with 10 trials, the experiment proper started. A trial began with a fixation cross centred on the screen for 1.75 s, followed by the stimulus for 1.5 s. Three asterisks followed, indicating a blinking moment for 1.5 s, followed by an empty screen for 0.5 s. The trials were divided into eight blocks with self-paced breaks in between.

MEG Procedure

The MEG system (CTF VSM MedTech) contained 275 axial gradiometers. The horizontal and vertical electrooculogram was recorded using two pairs of Ag/AgCl-electrodes. Surface electromyogram was recorded from the orbicularis oris muscle (electrode placement: left upper and right lower corner of the mouth). Three localisation coils were fixed to the nasion, left, and right ear canal to monitor the position of participants' heads relative to the gradiometers. Head localisation was performed in real-time and the head position was re-adjusted when needed to remain in the initial position (Stolk *et al.*, 2013). The data were low-pass filtered by an anti-aliasing filter (300 Hz cutoff), digitised at 1200 Hz, and stored for offline analysis. A microphone in the magnetically shielded room was connected to a computer, which controlled stimulus presentation with the software package Presentation (Neurobehavioral Systems). Anatomical MRIs of the participants' brains were acquired with a 1.5 T Siemens Magnetom Sonata system. To optimise the alignment of the MRI with the MEG data, the same ear plugs were used during the MEG session and the MR session.

RT Analysis

Vocal responses were evaluated in real time. Responses containing disfluencies or errors were coded as invalid and their corresponding trials excluded from all analyses. We submitted RTs to analyses of variance on the average naming RTs across participants (F_1) and across items (F_2), with distractor type as an independent variable. Paired-samples t-tests were used to evaluate the Stroop-like (related vs. identity) and the semantic (related vs. unrelated) effects. Additionally, 95% confidence intervals around the mean, calculated from the variance over participants, are reported.

MEG data analysis

Preprocessing. The MEG analyses were performed using FieldTrip (Oostenveld *et al.*, 2011). The data were down-sampled offline to 600 Hz. Power line fluctuations were estimated and subtracted from the data by fitting narrow-band sinusoidal functions at 50, 100 and 150 Hz. For the stimulus-locked analyses, the data were segmented into epochs from 1 s pre-stimulus to 1 s post-stimulus. For the response-locked analyses, we segmented

the data by using the RT of each individual trial. The resulting epochs ranged from 1 s before the response until the RT itself, now the 0-ms point. All epochs were inspected individually. Epochs containing ocular artefacts, SQUID jumps, and mouth EMG artefacts were detected based on sudden deviations from the ongoing signal and localisation on sensors, and subsequently removed (27% of the data, including trials excluded from the RT analysis). Excessively noisy channels were also removed.

Sensor-level analysis. Synthetic planar gradients were calculated (Bastiaansen & Knösche, 2000), on which all subsequent sensor-level analyses were performed. Using the combined planar gradient representation of the magnetic fields, the amplitude of the signal on the scalp is largest above the actual sources, facilitating the interpretation of sensor topographies. Moreover, sensor-level group analysis is facilitated and statistical sensitivity is increased.

Induced activity. For the stimulus-locked activity, TFRs of power were computed between 200 ms pre- to 1 s post-stimulus, at frequencies between 2 and 30 Hz. For the response-locked analysis, TFRs of power were computed over the whole segment length, at frequencies between 2 and 30 Hz. We used a sliding time window of three cycles' length (e.g., the window was 300 ms long at 10 Hz), advancing in steps of 50 ms and of 1 Hz. The data in each time window was multiplied with a Hanning taper before estimating power with the fast Fourier transform (FFT).

Evoked activity. Only the stimulus time-locked trials with RTs larger than 600 ms were entered in the analyses to prevent contamination of the signal with motor artefacts. This step was not necessary for the TFRs because motor artefacts have a specific spectral characteristic, that is, they contaminate temporal sensors with strong amplitude in frequencies ranging between 20 Hz and above (Goncharova *et al.*, 2003). For the ERFs, however, the activity is averaged across frequencies, making it impossible to detect motor artefacts in the signal. Therefore, an analysis that prevents motor contamination is warranted, as in the approach adopted here. The same number of trials for each distractor type was used (excessive trials were excluded randomly). Epochs were segmented consisting of 200 ms pre- to 800 ms post-stimulus (chosen for being shorter than the mean RTs). The data were filtered with a low-pass zero-phase shift Butterworth filter of 20 Hz and baseline corrected with the 200 ms pre-stimulus interval.

Statistical analysis. The sensor-level effects were statistically tested using a non-parametric cluster-based permutation approach (Maris & Oostenveld, 2007). This test provides a significant cluster (corrected for multiple comparisons) of adjacent time-points, sensors (and frequencies) that exhibit a similar difference across conditions. Given the hypothesis that the evoked activity in picture-word interference is similar to the classical N400, we constrained the analyses of the ERFs to a time window (350-650 ms) associated with the N400 effect (Kutas & Federmeier, 2011; Lau *et al.*, 2008), and to all left temporal MEG sensors (Lau *et al.*, 2008) that were available for all participants, following demonstrations that the N400m is especially prominent over left-temporal sensors (Hal-

gren *et al.*, 2002; Wang *et al.*, 2012). For the TFRs, given the lack of a-priori hypotheses, whole time epochs and all sensors that were available for all participants were entered in the analyses, but the frequency range was constrained to 4-12 Hz (Ewald *et al.*, 2012; Hanslmayr *et al.*, 2008).

Source-level analysis.

Anatomical processing. Due to technical failures during the measurements, head localisation was not performed for three participants, so the source-level analyses comprised 14 participants. From each participant's anatomical MRI, after segmentation using SPM, we constructed a realistically shaped single-shell model of the inside of the skull, serving as the volume conduction model. This triangulated boundary was subsequently used in combination with a geometric description of the potential neuronal sources (the source model) to compute the forward model (Nolte, 2003). For the reconstruction of the evoked activity we estimated the minimum-norm solution of a distributed source model, based on the individual cortical sheet, reconstructed using Freesurfer (Dale *et al.*, 1999) and downsampled to 8196 dipole locations using MNE-suite (Hämäläinen, Martinos Center for Biomedical Imaging, Massachusetts General Hospital, MA). For the reconstruction of the induced activity we used beamformers, scanning through a regular 3-dimensional grid of source locations with 1 cm resolution. Beamformers are especially suitable for analysing oscillatory activity (Liljeström *et al.*, 2005), but less so for evoked responses. Thus, we used the most suitable type of method for each type of activity (see for a similar approach Laaksonen *et al.*, 2012).

Induced activity. Source-level theta-band power was estimated using frequency domain beamforming (Gross *et al.*, 2001). A multitaper FFT with 2 Hz smoothing was applied to each trial segment (354-640 ms), and we selected the frequency bin centred at 7 Hz. The time window was chosen for being suitable for 2 cycles of 7 Hz oscillations. From the Fourier representation, the sensor-level cross-spectral density matrix was computed (for each effect we combined the two contrasted conditions in order to estimate the spatial filters specific for each effect), and the cross-spectral density matrices were used in combination with the leadfields to compute the spatial filters at each location of the 3-dimensional grid. The spatial filters were then applied to the Fourier transformed data from the individual conditions, allowing for a power estimate for each grid point, per participant, and per condition. The source locations showing local maxima over the whole brain in the reconstructed theta power were selected for further analysis (sources of interest). Using linearly constrained minimum variance beamforming (Van Veen *et al.*, 1997), we estimated the time course of the activations of neural sources at the selected locations. TFRs of the reconstructed activity were obtained using the same parameters as for the sensor-level TFRs. We used the time-frequency window of the significant theta activity on the sensor level (400-650 ms) to compute an average for each estimated source per participant. The averaged activity was tested with one-tailed paired-samples t-test for the Stroop-like (related > identity) and the semantic (related > unrelated) effects.

Evoked activity. The same trials entered in the sensor-level analyses were used for the minimum-norm reconstruction, but the epochs were further constrained from 200 ms pre- to 600 ms post-stimulus to avoid contamination from speech artefacts. The noise-covariance matrix was estimated based on the data from whole epochs (-200 to 600 ms) across distractor-type conditions and was used to regularise the inverse solution, and to compute noise-normalised estimates of neural activity. For the subsequent group analysis, the resulting estimates of neural activity were interpolated onto a regular 3-dimensional grid (8 mm resolution) and normalised to the MNI template brain, using SPM. First, a whole-brain analysis was conducted to identify brain areas associated with the modulations of the evoked activity as a function of distractor type. Based on the time windows identified in the sensor-level analyses, the interpolated and normalised minimum-norm estimates were averaged for each condition separately. The averaged activity was then contrasted between the relevant conditions. In a second analysis, in order to obtain the time course of the activity on the source-level data, we defined two sources of interest in left temporal cortex corresponding to the peaks in activity difference between the related and unrelated conditions and between the related and identity conditions. The signals coming from these two sources were then averaged across the sources for each condition separately.

4.3 Results

Picture naming RTs

The mean naming RTs (95% confidence intervals (CI) around the mean in brackets), measured from picture onset, were 911 ms [904,918], 894 ms [887,901], and 831 ms [824,838] for the related, unrelated, and identity conditions, respectively. A main effect of distractor type was found by participants, $F_1(2,32) = 57.2$, $p < .001$, and by items, $F_2(2,70) = 77.7$, $p < .001$. Pictures paired with related distractors were named more slowly than pictures paired with unrelated distractors (by participants, $t_1(16) = 3.9$, $p = .001$; by items, $t_2(35) = 2.5$, $p = .017$; 95% CI [9,30]) and more slowly than pictures paired with identity distractors (by participants, $t_1(16) = 9.7$, $p < .001$; by items, $t_1(35) = 14.8$, $p < .001$; 95% CI [64,100]). Furthermore, RTs were shorter in the identity than in the unrelated condition and participants became faster after the first stimulus presentation, but this decrease of RT was the same across conditions.

Induced activity

Sensor level. Figure 4.1A shows the results of the induced activity on the sensor level.

Stimulus-locked activity. As presented in Figure 4.1A, the TFRs show relative power increase in the 4-10 Hz range between 350-650 ms in left-hemisphere sensors. For the stimulus-locked TFRs, using a cluster-based permutation approach that was frequency, time, and channel uninformed (Maris & Oostenveld, 2007) while controlling for the false alarm rate, a statistically significant difference was revealed between the related and

identity conditions (Stroop-like effect, upper TFR) that could be attributed to a spectro-spatio-temporal cluster of adjacent frequencies, time-points, and channels that exhibited similar power increases in the related relative to the identity condition ($p = .012$). Moreover, a statistically significant difference was revealed between the related and unrelated conditions (semantic effect, lower TFR) that could be attributed to a spectro-spatio-temporal cluster of adjacent frequencies, time-points, and channels that exhibited similar power increases in the related relative to the unrelated condition ($p = .036$). These clusters were detected roughly between 400-650 ms post-stimulus in the 4-10 Hz range over the sensors highlighted in white in the scalp topographies in Figure 4.1A. Thus, the condition ordering of the theta power effect is in line with the ordering of mean RTs (related > unrelated; related > identity). The same power modulations were observed when the analysis was restricted only to trials with naming RTs larger than 600 ms. Moreover, a negative correlation was observed between the induced activity and RTs in the related condition such that the higher the frontal theta-power was, the faster participants named the pictures (see Supplementary materials of Piai *et al.*, 2014). This result is in line with the hypothesis that the observed theta-power increase is related to resolving lexical competition. A theta-power increase was also observed for the unrelated relative to the identity condition (see Supplementary materials of Piai *et al.*, 2014). Analyses of the phase-locking factor (Tallon-Baudry & Bertrand, 1999) indicated that the power effects were not associated with differences in phase-locked responses to the stimulus (see Supplementary materials of Piai *et al.*, 2014). Thus, this activity was likely induced by the stimulus as opposed to being evoked.

Response-locked activity. The response-locked analyses yielded a similar pattern of power changes as for the stimulus-locked activity. The TFRs presented in Figure 4.2 show relative power increase in the 4-10 Hz range between 400-200 ms before response onset. Significant spectro-spatio-temporal clusters were detected for the Stroop-like effect ($p = .004$) and for the semantic effect ($p = .032$). The condition ordering of the power effect is in line with the condition ordering of the mean RTs (related > unrelated; related > identity). The convergence between stimulus- and response-locked analyses indicates that the TFR effects observed were not induced by motor preparation and execution.

Source level. Figure 4.1B shows the results of the induced activity on the source level. The estimated sources (Gross *et al.*, 2001) of the Stroop-like effect, shown in the upper middle panel of Figure 4.1B, comprise the left postcentral gyrus [MNI peak activity: -50 -20 40] and the left superior frontal gyrus (SFG) [MNI peak activity: -10 30 50]. This latter source was also estimated for the semantic effect (lower middle panel of Figure 4.1B). The induced activity in these sources was estimated for each distractor-type effect (Van Veen *et al.*, 1997). In SFG, the averaged activity in the theta band (4-8 Hz) between 400-650 ms was significant for the Stroop-like effect (right upper panel of Figure 4.1B), $t(13) = 2.4$, $p = .018$, and for the semantic effect (right lower panel of Figure 4.1B), $t(13) = 2.2$, $p = .025$. In the postcentral gyrus, the averaged activity was significant for the Stroop-like effect (left upper panel of Figure 4.1B), $t(13) = 2.1$, $p = .029$, but non-

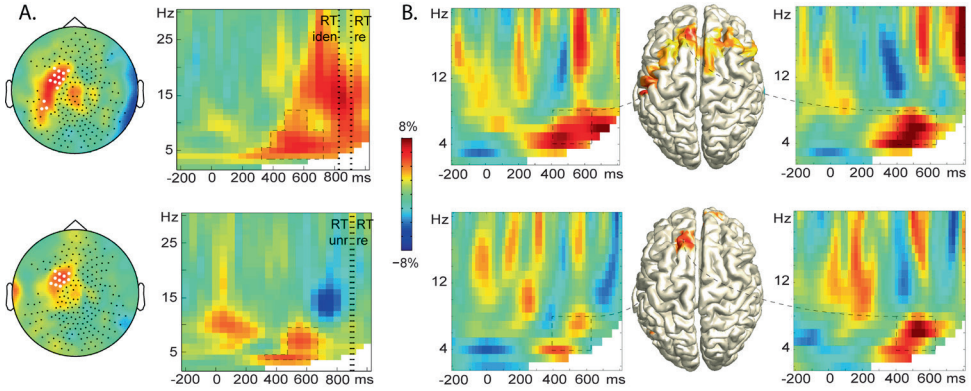

Figure 4.1: Induced brain responses. **A.** Stimulus-locked time-frequency representations of power for Stroop-like (upper) and semantic (lower) effects, averaged over the significant sensors (highlighted in white in the corresponding topographic maps to the left). Dashed vertical lines indicate the response times for the conditions. RT = response time; iden = identity condition; re = related condition; unr = unrelated condition. **B.** Estimated sources in the whole-brain analysis for the Stroop-like (upper middle panel) and semantic (lower middle panel) effects. The left and right panels show the time-frequency representation of the activity in the estimated sources. Dashed rectangles enclose the cluster of interest.

significant for the semantic effect (left lower panel of Figure 4.1B), $p = .216$. Thus, the semantic and Stroop-like effects share a source in SFG. Importantly, the induced effects are significant already in the sensor-level analysis, but the source analysis corroborates the findings.

Evoked activity

Sensor level. As expected, a peak around 450 ms after picture-word onset was observed in left-temporal sensors, as shown in Figure 4.3A. Using a time and sensor informed (350-550 ms, grey area in Figure 4.3A; left temporal sensors highlighted in black in the left layout) non-parametric cluster-based permutation test (Maris & Oostenveld, 2007), we observed a statistically significant difference between the related and identity conditions that could be attributed to a spatio-temporal cluster of adjacent time-points and channels that exhibited a larger ERF amplitude for the related than for the identity conditions ($p = .008$). This cluster was detected between 375 ms and 430 ms over the sensors highlighted in white in the upper right topography. Moreover, a statistically significant difference was revealed between the related and unrelated conditions that could be attributed to a spatio-temporal cluster of adjacent time-points and channels that exhibited a smaller ERF amplitude for the related than for the unrelated conditions ($p = .032$). This cluster was detected between 375 ms and 400 ms over the sensors highlighted in white in the lower right topography. The topographical maps of the amplitude differences are shown to the

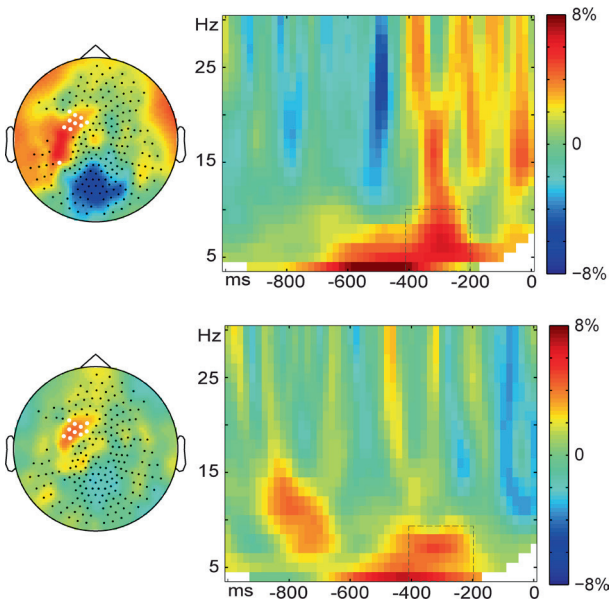

Figure 4.2: Induced brain responses time-locked to the onset of the naming responses. Response-locked time-frequency representations of power for Stroop-like (upper) and semantic (lower) effects, averaged over the significant sensors (highlighted in white in the corresponding topographic maps).

right for the Stroop-like (upper map) and semantic (lower map) effects. Similar effects were observed when the onset of EMG activity from the mouth was used to determine the duration of the segments analysed. Finally, a smaller amplitude was obtained for the identity than for the unrelated condition (see Supplementary Figure S3 of Piai *et al.*, 2014). These results indicate an N400m component, the ERF equivalent of the N400 (Halgren *et al.*, 2002), and are in line with the predicted relative effort of processing the picture-word stimuli.

Source level. Figure 4.3B presents the sources for the Stroop-like (upper) and semantic (lower) effects in the time windows identified in the sensor-level analyses. As can be seen, the estimated sources comprise superior and middle temporal cortex. The signals from these two sources were then extracted and averaged for each condition separately. As shown in Figure 4.3C, the distractors modulated the activity in these sources roughly between 300-500 ms after picture-word onset, with a peak around 400 ms. Note that the source analysis corroborates the sensor-level results but it does not imply that left MTG is the only source of the N400m component in picture naming.

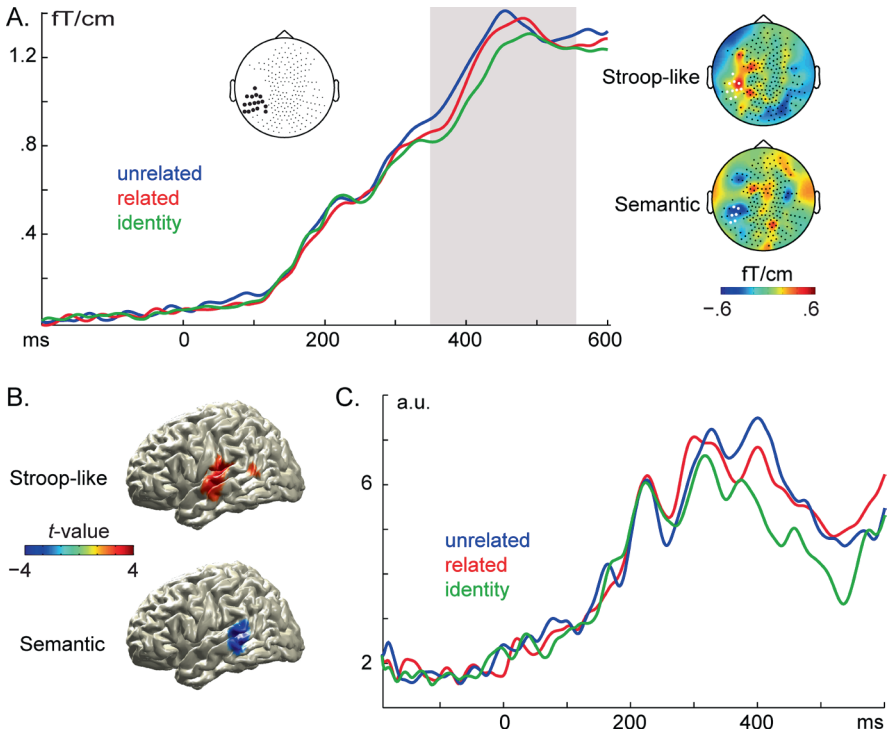

Figure 4.3: Evoked brain responses. **A.** Event-related fields for the distractor types, averaged over the left temporal sensors highlighted in the upper layout. The scalp topographies show the difference between conditions averaged in the time window of the corresponding significant temporal cluster with the sensors participating in the cluster highlighted in white. **B.** Estimated sources of the Stroop-like (upper) and semantic (lower) effects in the whole-brain analysis in the time window of the corresponding significant temporal cluster. Difference t-value maps were thresholded at the corresponding t-value for an alpha level = .05. **C.** Activity from the left temporal cortex for the distractor types.

4.4 Discussion

As outlined previously, a prominent theory of word production holds that word retrieval involves the activation of a set of candidate words in left middle temporal cortex, and a competitive selection of the intended word from this set regulated by frontal cortical mechanisms (Levelt, 2001; Levelt *et al.*, 1999; Roelofs, 2003; Roelofs & Hagoort, 2002; Roelofs & Piai, 2011). Previous electrophysiological studies reporting an N400 effect (Blackford *et al.*, 2012; Dell'Acqua *et al.*, 2010; Greenham *et al.*, 2000), examining only evoked brain activity, have provided evidence for the activation of multiple alternative words, but have not identified brain responses reflecting the competition caused by the activation of multiple alternatives. Furthermore, although previous fMRI studies have

shown the involvement of frontal cortex in competition resolution, little is known about the time course of its involvement. The present results characterised a neuronal substrate associated with competition as well as its broad time course. Competition was reflected by induced activity, localised to left superior frontal gyrus (SFG), showing an oscillatory power increase in the 4-10 Hz range between 400-650 ms. Activity was larger for the related than unrelated and identity conditions, suggesting different degrees of effort in resolving the competition among the alternative words, as reflected in the RTs.

Additionally, we observed evoked brain activity in left temporal cortex showing differential modulation peaking around 400 ms after picture-word onset. Activity was larger for the unrelated than related and identity conditions, suggesting different degrees of effort (priming) in processing the candidate words activated by the picture-word stimuli. This latter finding is in line with both the competitive and noncompetitive accounts, which propose that in the related condition, picture and word prime each other (e.g., Finkbeiner & Caramazza, 2006b; Levelt *et al.*, 1999; Roelofs, 2003). The observed sensor-level evoked brain activity agrees with previous ERP studies of picture-word interference (Blackford *et al.*, 2012; Dell'Acqua *et al.*, 2010; Greenham *et al.*, 2000) and the prevailing processing-effort interpretation of the N400 effect (Kutas & Federmeier, 2011; Lau *et al.*, 2008). Moreover, in agreement with previous reports of the generators of the N400 in language comprehension (Lau *et al.*, 2008; Tse *et al.*, 2007) and lexical activation in language production (Indefrey, 2011; Indefrey & Levelt, 2004; Levelt, 2001; Levelt *et al.*, 1999; Maess *et al.*, 2002), the distractor-type modulations were observed in an area comprising the left MTG. The finding of attenuated activity for the related condition relative to the unrelated condition also agrees with fMRI findings showing reduced left MTG activity for related relative to unrelated picture-word stimuli (de Zubicaray *et al.*, 2013). Although this activity could also be related to the activation of concepts, the left MTG source is more compatible with lexical activation rather than the activation of concepts (Indefrey & Levelt, 2004; Schwartz *et al.*, 2009). Our results show that the evoked and induced brain activity largely overlap in time, although they are differentially modulated by the distractor words and associated with different brain sources.

The observed induced activity in the theta band, localised to left SFG (possibly also including the most anterior portion of the supplementary motor area (pre-SMA) and the anterior cingulate cortex (ACC)), agrees with previous findings on executive control processes in various frontal areas (Aarts *et al.*, 2009; du Boisgueheneuc *et al.*, 2006; Nigbur *et al.*, 2011; Sauseng *et al.*, 2005, 2010; Stuss *et al.*, 2001). Theta oscillations have moreover been associated with manipulations of task-relevant information by executive control processes (Hanslmayr *et al.*, 2008; Nigbur *et al.*, 2011; Sauseng *et al.*, 2005, 2010). For example, theta-band effects in the ACC have previously been observed in manual Stroop task performance, where power increased with increasing competition between 400 and 800 ms after stimulus onset (Hanslmayr *et al.*, 2008). Although the spatial resolution of our source analyses using MEG is relatively low compared to fMRI (Hämäläinen *et al.*, 1993; Hillebrand *et al.*, 2005; Van Veen *et al.*, 1997), our frontal source also agrees with

previous fMRI studies, which related activity in left SFG and pre-SMA to effort in lexical selection (Alario *et al.*, 2006), and activity in left SFG to competition in Stroop-like tasks (Aarts *et al.*, 2009; Derrfuss *et al.*, 2005). Moreover, lesion-deficit analyses have related bilateral SFG to impaired performance on the colour-word Stroop task (du Boisgueheneuc *et al.*, 2006) and left SFG to executive control processes in working memory (Stuss *et al.*, 2001).

The resolution of lexical competition has also been associated with left inferior frontal gyrus (LIFG) in both fMRI and lesion-deficit analyses (Schnur *et al.*, 2009) using the blocked-cyclic naming paradigm, which was not found to be active in the present study. It should be noted that activity in LIFG has been found in some fMRI studies of picture-word interference (de Zubicaray *et al.*, 2009; see also Spalek & Thompson-Schill, 2008, who used a modified version of this task), but certainly not all (de Zubicaray *et al.*, 2001, 2002, 2013). It is possible that the present MEG study was insufficiently powerful or sensitive to detect the activity in LIFG. Alternatively, it may be that the picture-word interference task engages the LIFG less strongly than the blocked-cyclic naming task, perhaps because it does not rely on the same top-down biasing mechanism for selection as blocked-cyclic naming does (see Belke & Stielow, 2013), an issue that may be examined in future studies. Crucially, previous fMRI and lesion-deficit analyses (de Zubicaray & McMahon, 2009; de Zubicaray *et al.*, 2013; Schnur *et al.*, 2009; Spalek & Thompson-Schill, 2008) did not identify the temporal relation between left MTG activity (lexical activation processes) and frontal activity (competition resolution processes). The present results generally agree with existing findings, but importantly, provide evidence on the temporal dynamics of left superior/middle temporal and left frontal activity, suggesting a tight temporal link between the two. The tight temporal relation between these two activities is in line with an account in terms of lexical activation and competition resolution (Levelt, 2001; Levelt *et al.*, 1999; Roelofs, 1992, 2003; Roelofs & Hagoort, 2002).

The modulations of brain activity reported here (around 400 ms in the evoked activity) appear rather late in comparison to previous findings on evoked activity associated with language production (Aristei *et al.*, 2011; Costa *et al.*, 2009; Dell'Acqua *et al.*, 2010; Maess *et al.*, 2002). However, the early evoked responses reported by Dell'Acqua et al. were associated with early visual processing of the distractor word, whereas activity in the N400 time window was interpreted in terms of lexical activation (Dell'Acqua *et al.*, 2010), in line with our interpretation and the interpretation of Blackford et al. (2012). Note that Aristei et al., Costa et al., and Maess et al. did not have visual distractors. Timing estimates of lexical selection (Indefrey, 2011; Indefrey & Levelt, 2004) are based on studies of picture naming without visual word distractors. Picture-naming RTs in the picture-word interference task are typically 100 to 200 ms longer than in standard picture naming. Thus, it is plausible to assume that the presence of visual distractors prolongs perceptual processing, also delaying the onset of lexical selection (Indefrey, 2011; Piai *et al.*, 2012b, Chapter 6 of this dissertation). Under this assumption, the timing of the reported modulations is in line with previous studies.

4.4.1 Evaluating the noncompetitive account

We associated the evoked and induced brain activity with, respectively, the activation of a set of candidate words and the competitive selection of the intended word from this set. The tight temporal link between these two activities, and their timing relative to articulation onset, is especially important in light of an alternative account of word retrieval (Finkbeiner & Caramazza, 2006a,b; Janssen *et al.*, 2008), according to which a word is selected if its activation exceeds some threshold, but selection is assumed to be independent of the activation state of other words. The semantic effect is assumed to arise after word planning, reflecting the exclusion of a motor programme for the distractor word from an articulatory buffer (Finkbeiner & Caramazza, 2006b; Janssen *et al.*, 2008). This exclusion process is assumed to take longer when the distractor is semantically related to the picture than when it is unrelated, yielding the semantic interference effect in the naming RTs.

Previous fMRI studies (de Zubicaray & McMahon, 2009; de Zubicaray *et al.*, 2013) could not adjudicate between the competitive and noncompetitive accounts because no precise time information is obtained with this method. However, our results of the response-locked analyses do help adjudicate between the two accounts. According to the noncompetitive response-exclusion account, the interference effect emerges at the point of deciding between the motor programmes of the target and distractor in the output buffer (Finkbeiner & Caramazza, 2006a; see also Janssen *et al.*, 2008). Thus, interference arises when the motor programme has been derived for the picture and the programme for the distractor word is in the buffer. The presumed greater difficulty of deciding between motor programmes in the related than unrelated condition yields the semantic interference in RTs. According to time estimates from meta-analyses (Indefrey, 2011; Indefrey & Levelt, 2004), picture naming planning reaches the articulatory buffer no earlier than about 145 ms before articulation onset. Thus, according to the noncompetitive account, brain activity that reflects interference (i.e., activity that is in line with the condition ordering of RTs) should occur no earlier than about 145 ms before speech onset. However, the modulations of oscillatory power observed in our response-locked analyses already occurred between 400-200 ms before articulation onset, which is too early to be in agreement with the noncompetitive account. According to a different version of the response-exclusion account, the removal process starts as soon as the motor programme for the distractor reaches the articulatory buffer: "When the response to the distractor still occupies the buffer when the response to the picture becomes available, picture naming has to be postponed until the initial response is purged from the buffer" (Dhooge & Hartsuiker, 2010, p. 887). One could perhaps argue that the induced brain activity that we observed reflects this immediate removal process rather than reflecting the decision between two motor programmes in the buffer only. Dhooge and Hartsuiker observed that when a distractor word is presented 200 ms before picture onset, the distractor word still affects picture naming RTs (with mean picture naming RTs around 600 ms). This effect can only be obtained in the RTs if the exclusion process is still ongoing when picture name planning

reaches the buffer, which is around 455 ms after picture onset (with a mean RT of 600 ms, Indefrey & Levelt, 2004). This implies that the exclusion process takes at least some 655 ms (i.e., 455 + 200 ms) from the moment that the motor programme for the distractor reaches the buffer. This prediction is also not borne out by our data, which indicate that the induced activity is confined to a restricted time window, between 400 and 650 ms after picture onset.

To conclude, our findings are not in agreement with any of the versions of the response exclusion account in the literature (i.e., Dhooge & Hartsuiker, 2010; Finkbeiner & Caramazza, 2006b; Janssen *et al.*, 2008). This is in line with the accumulating empirical evidence against this hypothesis (e.g., Abdel Rahman & Melinger, 2009b,a; Abdel Rahman & Aristei, 2010; Hantsch & Mädebach, 2013; La Heij *et al.*, 2006; Mädebach *et al.*, 2011; Mulatti & Coltheart, 2012; Hutson *et al.*, 2013; Roelofs *et al.*, 2011b, 2013; Roelofs & Piai, 2013; Starreveld *et al.*, 2013, and Chapters 2 and 3).

4.4.2 Evaluating the competition account by computer simulations

Blackford et al. (2011) stated that "the electrophysiological evidence for semantic priming in the presence of behavioral interference provides evidence against an account of selection by competition at the lemma level" (p. 97). They assumed that the picture name is primed by the distractor word. However, we assume that, in addition, the distractor word is primed by the picture (i.e., reverse priming, making related words more potent competitors than unrelated words). This assumption is in line with the evidence that both pictures and words evoke an N400 response (for reviews, see Kutas & Federmeier, 2011; Lau *et al.*, 2008). Using the WEAVER++ model of word production, Roelofs (1992) presented the results of computer simulations demonstrating that the semantic interference effect in RTs can be explained by reverse priming combined with the assumption that a word becomes available for selection only if its activation exceeds that of competitor words by a critical amount (the response threshold). Moreover, computer simulations by Roelofs et al. (2006) using this model demonstrated that if frontal cortex is involved in top-down enhancing the activation of the target until its activation exceeds the selection threshold, the patterns of frontal activity typically observed in Stroop-like tasks are explained.

To demonstrate that this competitive-selection account explains the electrophysiological evidence for semantic priming in the presence of behavioural interference in the present study, we conducted computer simulations using WEAVER++. The simulation protocol and parameters were exactly the same as in earlier simulations using the model (e.g., Levelt *et al.*, 1999; Roelofs, 1992, 2003; Roelofs & Hagoort, 2002; Roelofs *et al.*, 2006) except that the response threshold was set at 2.0 to fine-tune the fit to the data. The results of the simulations along with the present empirical results are shown in Figure 4.4. In line with the observed results, the model yields longer RTs for the related than for the unrelated condition and shorter RTs for the identity than for the unrelated

condition (Figure 4.4A). Moreover, in line with the observed results, the model yields more priming in the identity than in the related condition, and both conditions show more priming than the unrelated condition (Figure 4.4B). Priming in the model is depicted as the difference in peak activation between conditions. The simulation results corroborate our account of the present findings in terms of lexical activation and competition.

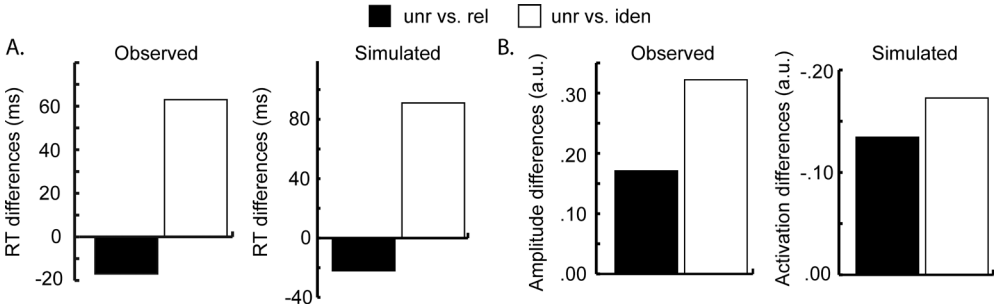

Figure 4.4: Observed results and WEAVER++ simulations. **A.** Differences in picture-naming times as empirically observed and from the simulations for the related condition (black bar) and identity condition (white bar) relative to the unrelated condition. **B.** Differences in signal amplitude of the left temporal cortex activity for the related condition (black bar) and identity condition (white bar) relative to the unrelated condition and corresponding priming effects in the simulations. RT = response time; unr = unrelated; rel = related; iden = identity.

To conclude, we obtained evidence that evoked (i.e., phase-locked) activity in left temporal cortex and induced (i.e., non-phase-locked) activity in superior frontal cortex, respectively, characterise lexical activation and competitive selection in overt picture naming. These findings support the theory of lexical selection by competition.

CHAPTER 5

Locus of Semantic Interference in Picture Naming: Evidence from Dual-Task Performance

Disagreement exists regarding the functional locus of semantic interference of distractor words in picture naming. This effect is a cornerstone of modern psycholinguistic models of word production, which assume that it arises in lexical response-selection. However, recent evidence from studies of dual-task performance suggests a locus in perceptual or conceptual processing, prior to lexical response-selection. In these studies, participants manually responded to a tone and named a picture while ignoring a written distractor word. The stimulus onset asynchrony (SOA) between tone and picture-word stimulus was manipulated. Semantic interference in naming latencies was present at long tone pre-exposure SOAs, but reduced or absent at short SOAs. Under the prevailing structural or strategic response-selection bottleneck and central capacity sharing models of dual-task performance, the underadditivity of the effects of SOA and stimulus type suggests that semantic interference emerges before lexical response-selection. However, in more recent studies, additive effects of SOA and stimulus type were obtained. Here, we examined the discrepancy in results between these studies in six experiments in which we systematically manipulated various dimensions on which these earlier studies differed, including tasks, materials, stimulus types, and SOAs. In all our experiments, additive effects of SOA and stimulus type on naming latencies were obtained. These results strongly suggest that the semantic interference effect arises after perceptual and conceptual processing, during lexical response-selection or later. We discuss several theoretical alternatives with respect to their potential to account for the discrepancy between the present results and other studies showing underadditivity.

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5.1 Introduction

An important question in the psychology of language concerns how speakers select from memory the words that they want to produce. This ability, called lexical selection, is a topic of much research in the field of word production. One way of studying lexical selection consists of presenting participants with pictured objects paired with superimposed distractor words, a paradigm called picture-word interference (PWI) (see for reviews Abdel Rahman & Melinger, 2009b; Glaser, 1992; Roelofs, 2007). Participants are instructed to name the pictures and to ignore the distractors. The relation the distractor word bears with the picture name (e.g., semantic, phonological, etc.) is manipulated and effects obtained are thought to inform researchers about processes involved in word production.

One specific effect has long been assumed to provide evidence about the nature of lexical selection: semantic interference (e.g., Damian & Martin, 1999; Levelt *et al.*, 1999; Roelofs, 1992; Schriefers *et al.*, 1990; Starreveld & La Heij, 1996). This effect concerns the finding that response times (RTs) are longer for picture naming when the distractor is from the same semantic category as the picture (pictured cat, word *dog*) relative to unrelated distractors (pictured cat, word *pen*). A prominent account of this effect places it at the stage of lexical selection (e.g., Levelt *et al.*, 1999). This account has been computationally implemented in several models, including the WEAVER++ model (Levelt *et al.*, 1999; Roelofs, 1992, 2003, 2007, 2008a,c) and the model of Starreveld and La Heij (1996).

The assumption that the semantic interference effect arises during lexical selection was recently challenged by Dell'Acqua, Job, Peressotti, and Pascali (2007). These authors used PWI as part of a psychological refractory period (PRP) procedure (Pashler, 1984, 1994) to determine at which stage the semantic interference effect emerged. With the PRP procedure, participants have to respond quickly and accurately to two stimuli (S1 and S2) in the right order, that is, the response to S1 has to be given before the response to S2. The stimulus onset asynchrony (SOA) between S1 and S2 is varied. A common finding in PRP experiments is that RTs for the second task increase as the SOA between S1 and S2 decreases, reflecting dual-task interference. The participants of Dell'Acqua et al. performed a manual tone discrimination task (Task 1), followed by a PWI task (Task 2) with distractor words semantically related or unrelated to the picture, using SOAs of 100, 350 or 1000 ms. The authors observed a semantic interference effect and an SOA effect, that is, picture-naming RTs increased as SOA decreased. Moreover, they also observed that the effects of SOA and stimulus type (semantically related or unrelated to the picture) were underadditive, that is, the semantic interference effect was smaller at the 350-ms SOA (23 ms) than at the 1000-ms SOA (68 ms), and absent at the 100-ms SOA (-7 ms). These findings were replicated by Ayora and colleagues (2011) using SOAs of 100 and 1000 ms and by Van Maanen, Van Rijn, and Taagten (2012, Experiment 1), using SOAs of 100, 350, and 800 ms.

This underadditivity of the effects of SOA and stimulus type on mean naming RTs was explained by Dell'Acqua and colleagues following the dominant model of PRP

performance in the literature, which assumes that, in the context of overlapping tasks, response selection constitutes a processing bottleneck (Pashler, 1984, 1994). That is, only one response can be selected at a time. Thus selecting a response for Task 2 (PWI) has to wait until a response for Task 1 (tone discrimination) has been selected. This waiting period is known as *slack* (Schweickert, 1980). When there is enough time between the two tasks (i.e., the SOA between S1 and S2 is long), there is no overlap in selecting a response in each task, so an RT effect that is usually observed in single-task performance (e.g., semantic interference) is also observed in dual-task performance. Figure 5.1A depicts this situation assuming a response-selection bottleneck and a lexical response-selection locus of the semantic interference effect. Models of picture naming assume perceptual and conceptual encoding, lexical selection, word-form encoding, and articulation as the processing stages (e.g., Levelt *et al.*, 1999; Roelofs, 2003). Lexical selection in models of picture naming corresponds to response selection in models of dual-task performance (e.g., Roelofs, 2007, 2008a). This is also assumed by Dell'Acqua and colleagues. In the remaining of the present article, we denote perceptual and conceptual encoding as *pre-selection stages*, lexical selection as *response selection*, and word-form encoding and articulation as *post-selection* stages.

At short SOAs, Task 2 effects that emerge during or after the response-selection bottleneck should be observed in the RTs. If the semantic interference effect in Task 2 arises during response selection, there will be no slack to absorb the effect. Consequently, semantic interference should be of similar magnitude at short and long SOAs. This situation of additivity of effects is depicted in Figure 5.1B (for a short SOA of 0 ms). In contrast, if semantic interference in Task 2 occurs before response selection (i.e., during stages of perceptual and conceptual encoding), the effect will be "absorbed into slack" (Pashler & Johnston, 1998, p. 170). This situation is depicted in Figure 5.1C.

The absorption of Task 2 effects into slack corresponds to what was observed by Dell'Acqua et al. (2007) for the semantic interference effect, suggesting a pre-selection locus of the effect (i.e., during perceptual and conceptual stages). In contrast, using the classic colour-word Stroop task as Task 2 (i.e., naming the ink colour of incongruent or congruent colour words), Fagot and Pashler (1992, Experiment 7) found that the Stroop effect (longer RTs in the incongruent condition, e.g., *blue* printed in red ink, relative to the congruent condition, e.g., *red* printed in red ink) was of similar magnitude at short and long SOAs. This confirms earlier evidence that the Stroop effect arises during response selection (see MacLeod, 1991, for a review), which corresponds to the stage of lexical selection in models of word production (e.g., Roelofs, 2003). According to Dell'Acqua et al., the fact that semantic interference is absorbed into slack, whereas the Stroop effect is not, suggests that the semantic interference effect emerges during perceptual or conceptual processing (i.e., pre-selection). This observation challenges the account of Roelofs (2003) implemented in WEAVER++, which assumes that semantic interference and the colour-word Stroop effect both arise in lexical response-selection.

However, in a recent study, Schnur and Martin (2012) failed to replicate the underadditivity of stimulus type and SOA effects on the mean naming RTs. They conducted

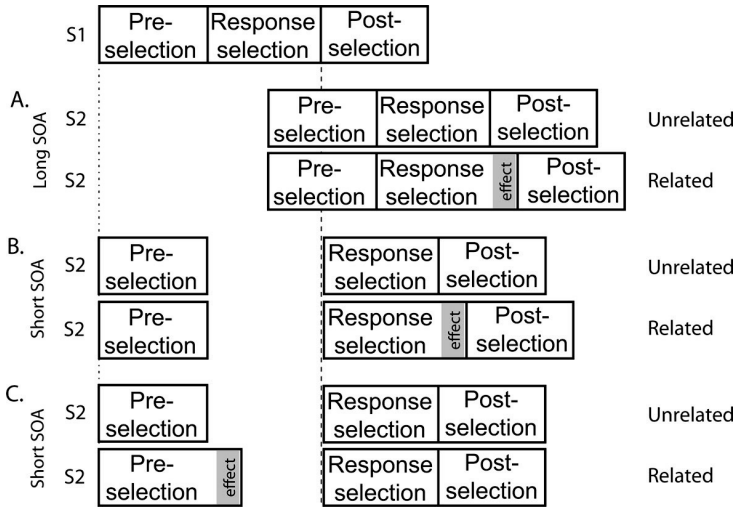

Figure 5.1: Schematic illustration of a lexical response-selection bottleneck account of the stimulus onset asynchrony (SOA) effect on semantic interference in dual-task performance. **(A)** At long SOAs, the semantic interference of distractor words in Task 2 picture naming is observed in the RTs, regardless of whether the locus of the effect is in response selection, as indicated, or earlier. **(B)** If the semantic interference effect arises during lexical response-selection, then at short SOAs (here SOA of 0 ms), it is not absorbed into slack and, thus, observed in the RTs. **(C)** If the semantic interference effect arises during perceptual/conceptual (pre-selection) processing, then at short SOAs (here SOA of 0 ms), it is absorbed into slack and, thus, not observed in the RTs. S1 = Stimulus 1. S2 = Stimulus 2.

two experiments with different materials and slightly different experimental parameters than Dell'Acqua and colleagues. In both experiments, equivalent semantic interference effects were obtained at short and long SOAs (31 ms on average) following tone presentation requiring a manual response. Thus, Schnur and Martin obtained additive effects of SOA and stimulus type, compatible with Figure 1B. Furthermore, Piai and Roelofs (2013) also failed to replicate the underadditivity of stimulus type and SOA effects using the SOAs of 0 and 1000 ms.[1] These results suggest a response-selection or post-selection locus of semantic interference under the assumption of a response-selection bottleneck.

To summarise, whereas three experiments obtained underadditive effects of SOA and stimulus type (Ayora *et al.*, 2011; Dell'Acqua *et al.*, 2007; van Maanen *et al.*, 2012),

[1] Piai and Roelofs (2013) conducted a main PWI experiment with Stroop-like (related vs. congruent) and semantic (related vs. unrelated) manipulations and a control experiment with a semantic manipulation. They obtained additive effects of SOA and the Stroop-like manipulation. The effect of SOA and the semantic manipulation was overadditive in the main experiment and additive in the control experiment. Thus, overall, the effects of SOA and stimulus type were additive rather than underadditive. This study is not reported in the present dissertation because its main research question falls outside the scope of the work presented here.

three other experiments obtained additive effects (Piai & Roelofs, 2013; Schnur & Martin, 2012). The underadditivity of effects suggests a pre-selection locus of the semantic interference effect, whereas the additivity suggests a locus at lexical response-selection or a later stage. Given the prominent role played by the semantic interference effect in informing theories of language production (e.g., Abdel Rahman & Melinger, 2009b; Janssen *et al.*, 2008; Levelt *et al.*, 1999), this discrepancy in the literature needs to be resolved.

There are at least two possible explanations for the discrepancy between studies. First, it may be the case that these studies made a Type-I or Type-II error. A Type-II error in the experiments of Dell'Acqua and colleagues (Ayora *et al.*, 2011; Dell'Acqua *et al.*, 2007) and Van Maanen et al. (2012) would involve a failure to detect a true full-blown semantic interference effect at the short SOA with their samples of participants. A Type-I error in the experiments of Schnur and Martin (2012) and Piai and Roelofs (2013) would involve the detection of a spurious full-blown semantic interference effect at the short SOA with their samples of participants. This explanation is, however, unlikely given that both additivity and underadditivity have been observed three times each.

The second possible explanation for the discrepancy lies in the nature of the processing bottleneck in dual-task performance. In the literature, the assumption of a structural response-selection bottleneck has been challenged (e.g., Hübner & Lehle, 2007; Israel & Cohen, 2011; Karlin & Kestenbaum, 1968; Lehle & Hübner, 2009; Leonhard & Ulrich, 2011; Meyer & Kieras, 1997a; Miller *et al.*, 2009; Navon & Miller, 2002; Pannebakker *et al.*, 2011; Schumacher *et al.*, 1999, 2001; Schvaneveldt, 1969; Tombu & Jolicoeur, 2003). According to one alternative account, dual-task interference arises because response-selection processes require central attentional capacity, which may be shared between tasks (Tombu & Jolicoeur, 2003). However, this account predicts additive effects of Task 2 response-selection manipulations and SOA (for extensive discussion, see Tombu & Jolicoeur, 2003), and therefore cannot explain why some studies obtained additive effects (Piai & Roelofs, 2013; Schnur & Martin, 2012) and other studies observed underadditive effects (Ayora *et al.*, 2011; Dell'Acqua *et al.*, 2007; van Maanen *et al.*, 2012, Experiment 1). According to another alternative account, the locus of the bottleneck is strategically determined (e.g., Hübner & Lehle, 2007; Israel & Cohen, 2011; Lehle & Hübner, 2009; Leonhard & Ulrich, 2011; Logan & Gordon, 2001; Meyer & Kieras, 1997a; but see Ruthruff *et al.* 2001; 2009) rather than structural and immutable, as argued by Dell'Acqua et al. (2007) and Pashler (1984, 1994). That is, a bottleneck may, in principle, occur at any stage, depending on the amount of overlap between tasks that participants (strategically) allow for. The overlap of response-selection processes for the two tasks may lead to underadditive effects of the Task 2 response-selection manipulation and SOA (e.g., Karlin & Kestenbaum, 1968; Schumacher *et al.*, 1999; Thomson *et al.*, 2010). It should be noted, however, that participants usually seem reluctant to select responses for Tasks 1 and 2 in parallel (e.g., often extensive practice with the two tasks is required), so that a response-selection bottleneck typically prevails in dual-task performance.

The strategic bottleneck account assumes that dual-task interference effects may differ between studies, because participants may differ in the strategic determination of

the amount of overlap between Task 1 and Task 2 (i.e., the locus of the bottleneck stage), as proposed in Chapter 2 (Piai *et al.*, 2011) and by Roelofs (2007, 2008a), and Roelofs and Piai (2011), following Meyer and Kieras (1997a,b). If the semantic interference effect arises in lexical selection and the participants of Dell'Acqua et al. (2007), Ayora et al. (2011), and Van Maanen et al. (2012, Experiment 1) allowed overlap between response selection in the tone and PWI tasks, then underadditive effects of SOA and stimulus type should be obtained, as empirically observed. In contrast, if the participants of Schnur and Martin (2012), Fagot and Pashler (1992), and Piai and Roelofs (2013) did not allow temporal overlap between the response selection processes, then additive effects of SOA and stimulus type should be obtained, as empirically observed in these studies. Schnur and Martin (p. 306) acknowledged that the strategic bottleneck account presented in Chapter 2 (Piai *et al.*, 2011) could provide an explanation for the discrepancy among studies. Moreover, to support such a strategic account, Schnur and Martin reported that participants who made more than 20% errors on Task 1 showed a tendency towards a pattern of underadditivity, possibly indicating differences in strategic scheduling of the tasks.

Recently, Kleinman (2013) proposed that a difference in phonological regularity of the distractor words between Dell'Acqua et al. (2007) and Schnur and Martin (2011), rather than a different locus of the bottleneck, caused the difference in semantic effects at short SOAs between studies. For phonologically regular words, the sequence of phonemes can be derived from the spelling by applying grapheme-phoneme correspondence rules, whereas for phonologically irregular words, this cannot be done. Whereas the spelling-to-sound mapping in Italian, the language used by Dell'Acqua et al., is regular, it is highly irregular for English, the language used by Schnur and Martin. According to Kleinman, at short SOAs, the phonologically regular distractor words of Dell'Acqua et al. could be processed concurrently with selecting a response for the tone, whereas the phonologically irregular distractors of Schnur and Martin could not. As a consequence, assuming a response-selection bottleneck and lexical response-selection locus of semantic interference, the distractor words were already processed before response selection in picture naming at short SOAs in the study of Dell'Acqua et al., eliminating semantic interference, whereas the distractor words were processed during response selection in picture naming in the study of Schnur and Martin, yielding semantic interference.

However, the spelling-to-sound mapping in Dutch, the language that we used (Piai & Roelofs, 2013), is also regular (Booij, 1995; Borgwaldt *et al.*, 2010; Nunn, 1998; Patel *et al.*, 2004; Seymour *et al.*, 2003). In the study of Piai and Roelofs (2013), the distractor words were phonologically regular. Still, the semantic interference effect was clearly present at the short SOA (i.e., 0 ms), in disagreement with the phonological regularity account of Kleinman (2013). Nevertheless, Piai and Roelofs report only one experiment, and it is important to examine whether their findings can be replicated. In the first five experiments in the present article, the distractor words were phonologically regular, allowing for an examination of whether the underadditivity predicted by

Kleinman is obtained or whether the additive findings of Piai and Roelofs are replicated.

5.1.1 Plan of the present study

Determining whether the semantic interference effect has a pre-selection (i.e., perceptual or conceptual) locus, as maintained by Dell'Acqua et al. (2007), or a locus at lexical-response selection or a later stage, as maintained by Schnur and Martin (2012), is important for our understanding of lexical access. The experiments of Ayora et al. (2011), Dell'Acqua et al. (2007), Fagot and Pashler (1992, Experiment 7), Kleinman (2013), Schnur and Martin (2012), Piai and Roelofs (2013), and Van Maanen et al. (2012) differ in several respects, including tasks, materials, SOAs, and stimulus types. The aim of the experiments reported in the present article was to examine whether any of these factors could have contributed to the difference in results between the earlier studies. Put differently, we investigate under which circumstances the additivity or underadditivity of the effects of SOA and stimulus type can be replicated, or whether additivity prevails regardless of the specific circumstances (suggesting a response-selection bottleneck and a response-selection or post-selection locus of the distractor effects).

Statisticians and investigators have pointed to the importance of replication of results for drawing theoretical conclusions (e.g., Cumming, 2008, 2012; Cumming & Maillardet, 2006; Fisher, 1966; Tukey, 1969). Cumming and Maillardet (2006) stated that considering whether an effect is replicable is at the heart of drawing inferences from data. (p. 217). Furthermore, although the additivity of the Stroop effect with SOA observed by Fagot and Pashler (Experiment 7) plays a crucial role in the theoretical argumentation of Dell'Acqua et al., there are no reported replications of this additivity in the literature.

We examined the discrepancy between the earlier studies of Ayora et al. (2011), Dell'Acqua et al. (2007), Fagot and Pashler (1992, Experiment 7), Kleinman (2013, Experiment 1), Schnur and Martin (2012), Piai and Roelofs (2013), and Van Maanen et al. (2012) in six new experiments manipulating various dimensions on which the earlier studies differed, including tasks (PWI, colour-word Stroop), materials (new materials vs. Dutch translations of the original materials used by Ayora et al.), stimulus types (related, unrelated, Stroop-like congruent, neutral), stimulus-set size (3, 32, 35), and SOAs (0, 100, 500, 1000 ms).

In Experiment 1, we directly compared PWI and colour-word Stroop task performance by having a single group of participants perform both tasks. In contrast, Dell'Acqua et al. compared PWI and Stroop task performance between different studies (i.e., Fagot & Pashler and themselves), which differed in several methodological respects. For example, Fagot and Pashler (Experiment 7) only had three colour-word stimuli presented in different conditions, whereas Dell'Acqua et al. had 48 picture stimuli. Moreover, relevant for the strategic bottleneck account (e.g., Meyer & Kieras, 1997a; Piai *et al.*, 2011; Roelofs & Piai, 2011; Schumacher *et al.*, 1999), out of order responding (i.e., Task 2 responses occurring before Task 1 responses) was more likely to occur in Fagot and Pashler's study than in Dell' Acqua et al.'s study for two reasons. First, the SOA

values used by Fagot and Pashler were shorter than the Task 1 mean RTs. Second, the experiment of Fagot and Pashler included congruent Stroop stimuli, which yield very short RTs. The higher probability of out-of-order responses could have invited the participants of Fagot and Pashler to adopt a more cautious scheduling strategy (i.e., adopting a response-selection rather than post-selection bottleneck), which may have yielded the additive effects in their study. In our Experiment 1, there were three pictures and three colours, presented in incongruent (e.g., pictured leg, word *arm*; colour red, word *green*), congruent (e.g., pictured leg, word *leg*; colour red, word *red*), and neutral conditions (e.g., pictured leg or colour red combined with five Xs). The SOA between tone and PWI or Stroop stimulus was 0 or 500 ms. The use of the SOAs of 0 and 500 ms is similar to the values used by Fagot and Pashler (1992), whose longest SOA was 450 ms.

In Experiment 2, we omitted the Stroop task, increased the number of PWI stimuli to 32, and included an additional unrelated condition (e.g., pictured leg, word *train*), which allowed for the assessment of Stroop-like effects (incongruent distractor *arm* vs. congruent distractor *leg*) and semantic effects (related distractor *arm* vs. unrelated distractor *train*). In this way, the stimulus-set size and the stimulus types used are similar to Dell'Acqua et al. In Experiment 3, we omitted the congruent condition so that only semantically related and unrelated conditions were included in the experiment, exactly as in the experiment of Dell'Acqua et al. According to Van Maanen et al. (2012), the presence or absence of congruent stimuli in an experiment leads to, respectively, a widening or narrowing of attention to the distractor word, which should yield additive effects in our Experiment 2 and underadditive effects in our Experiment 3. Experiment 4 had the same distractor conditions as Experiment 3, but we replaced the SOA of 500 ms by a longer SOA of 1000 ms, which corresponds to the longest SOA used by Dell'Acqua et al. and Schnur and Martin. Thus, the SOA values used now were longer than the Task 1 mean RTs, presumably decreasing the probability of out of order responses relative to the 500-ms SOA.

In Experiments 1-4, the proportions of trials with short and long SOAs were the same. However, Dell'Acqua et al. used two short SOAs (100 and 350 ms) and one long SOA. This difference could be relevant given the demonstration by Miller et al. (2009) that, as the proportion of short SOAs increases in an experiment, participants tend to shift away from serial processing towards a more parallel mode of processing. Therefore, in Experiment 5, we doubled the number of 0-ms SOA trials, so that the proportion of short and long SOAs corresponded to the study of Dell'Acqua et al. In Experiments 1 to 5, the distractor words were phonologically regular, which should yield underadditive effects of distractor type and SOA, according to Kleinman (2013).

In addition to the design difference among studies that we discussed above, there were several other dimensions on which the previous studies differed. One such difference concerned response-set membership of the distractor words, which is an important variable in Stroop-like interference tasks (e.g., Lamers *et al.*, 2010; Piai *et al.*, 2012a, Chapter 3). In Fagot and Pashler's (1992) study, the distractor words corresponded to responses in the experiment, whereas that was not the case in the studies of Dell'Acqua et al. (2007),

Ayora et al. (2011), Kleinman (2013), Schnur and Martin (2012), and Van Maanen et al. (2012). Moreover, the number of tones used also differed among studies: two tones in Fagot and Pashler (Experiment 7) and Piai and Roelofs (2013) and three tones in the studies of Dell'Acqua et al., Ayora et al., Kleinman, Schnur and Martin, and Van Maanen et al. Therefore, Experiment 6 was a replication of the design of Ayora et al. with the materials translated into Dutch and with SOAs of 100 and 1000 ms (Schnur & Martin used English translations of the materials of Ayora et al.).

In order to allow for an easy comparison of the properties of the present experiments with those published in the literature, Table 5.1 gives an overview over the commonalities and differences of the published experiments and of all experiments of the present article. In all experiments, we assessed whether the effects of SOA were additive or underadditive with the effects of Stroop or PWI stimulus type.

5.2 Experiment 1

Although the comparison between PWI and colour-word Stroop task performance played a critical role in the theoretical argumentation of Dell'Acqua et al. (2007), it is somewhat problematic, because their comparison is based on two studies (Dell'Acqua *et al.*, 2007 and Fagot & Pashler, 1992) that differ not only in the task (PWI versus Stroop task), but also in a number of other potentially relevant aspects. For example, the comparison involved different groups of participants performing the Stroop experiment of Fagot and Pashler (1992) and the PWI experiment of Dell'Acqua et al. Moreover, in the Stroop experiment, three colour stimuli were used, requiring only three different responses, whereas there were 48 different responses in the PWI experiment. The distractor words in the PWI experiment were not part of the response set (i.e., they were not actual responses) whereas in the Stroop experiment, all written words corresponded to actual responses. These methodological differences could have affected the outcomes, as explained above, a possibility that is explicitly examined in Experiment 1.

We therefore directly compared PWI and colour-word Stroop task performance by having a single group of participants perform both tasks. Stroop experiments typically have three or four colour stimuli, which are constantly repeated, whereas PWI experiments usually have around 30 pictures, repeated only a few times (if repeated at all). In the present experiment, there were three pictures and three colours. The distractors in PWI were manipulated as to resemble typical Stroop experimental conditions: incongruent (e.g., pictured leg, word *arm*; colour red, word *green*), congruent (e.g., pictured leg, word *leg*; colour red, word *red*), or neutral conditions (e.g., pictured leg or colour red combined with five Xs). The SOA between tone and PWI or Stroop stimulus was 0 or 500 ms. Table 5.1 presents the experimental parameters of Experiment 1.

Table 5.1: Experimental parameters of previous studies and of the present experiments. Exp = Experiment; Nr stim = number of stimuli; Picts = pictures; Resp = distractors in the response set; SOA = stimulus onset asynchrony.

	Nr stim	SOA values	Resp	Stimulus types	Tones
Ayora et al. (2011)	35 picts	100, 1000	No	Related, unrelated, phonologically related	300, 600, 1200 Hz, 50 ms
Dell'Acqua et al. (2007)	48 picts	100, 350, 1000	No	Related, unrelated	300, 600, 1200 Hz, 50 ms
Fagot & Pashler (1992)	3 colours	-50, 50, 150, 450	Yes	Congruent, incongruent	300, 800 Hz, 300 ms
Kleinman (2013)	27 picts	100, 350, 1000	No	Related, unrelated	300, 600, 1200 Hz, 50 ms
Piai & Roelofs (2013)	32 picts	0, 1000	Yes	Related, unrelated, congruent	300, 800 Hz, 300 ms
Schnur & Martin (2012)	48 picts	100, 350, 1000 (Exp 1a), 1500 (Exp 1b)	No	Related, unrelated	300, 600, 1200 Hz, 50 ms
Van Maanen et al. (2012)	49 picts	100, 350, 800	No	Related, unrelated, congruent (Exp 2)	300, 600, 1200 Hz, 150 ms
			Present study		
Exp 1	3 picts, 3 colours	0, 500	Yes	Congruent, incongruent, neutral	300, 800 Hz, 300 ms
Exp 2	32 picts	0, 500	Yes	Related, unrelated, congruent	300, 800 Hz, 300 ms
Exp 3	32 picts	0, 500	Yes	Related, unrelated	300, 800 Hz, 300 ms
Exp 4	32 picts	0, 1000	Yes	Related, unrelated	300, 800 Hz, 300 ms
Exp 5	32 picts	0 (larger %), 1000	Yes	Related, unrelated	300, 800 Hz, 300 ms
Exp 6	35 picts	100, 1000	No	Related, unrelated	300, 600, 1200 Hz, 50 ms

5.2.1 Method

Participants. Sixteen young adults (4 male, mean age = 20.1, *sd* = 2.3) from the participant pool of Radboud University Nijmegen participated in the experiment for course credits or monetary compensation. All participants were right-handed, native speakers of Dutch with normal or corrected-to-normal vision and normal hearing.

Materials and design. The picture stimuli were three black-and-white line drawings of the body parts leg, arm, and finger, taken from the picture gallery of the Max Planck Institute for Psycholinguistics, Nijmegen. In the congruent condition, these three pictures were presented with their Dutch basic-level names as distractors. These Dutch words (i.e., *been*, *arm*, and *vinger*) are phonologically regular (cf. Booij, 1995; Bosman *et al.*, 2006; Kerkhoff *et al.*, 1984; Nunn, 1998). The incongruent condition was formed by pairing the pictured leg with the distractor *finger*, the pictured finger with *arm*, and the pictured arm with *leg*. In the neutral condition, the three pictures were presented along with five Xs. The distractors were presented in white colour in lowercase Arial font, occupying on average 2.8° x 0.9° of visual angle at a viewing distance of approximately 60 cm, and the pictures were on average 5.7° x 5.7° of visual angle. The Stroop stimuli were the Dutch colour names for green, red, and blue (i.e., *groen*, *rood*, and *blauw*, all phonologically regular), printed in the corresponding ink colour, respectively, in the congruent condition, or printed in red, blue and green ink respectively in the incongruent condition. In the neutral condition, a series of five Xs was presented either in green, red or blue ink. The Stroop stimuli were presented in uppercase Arial font (on average 2.8° x 0.9° of visual angle). The pure tones were of 300 Hz (low tone) and of 800 Hz (high tone) and lasted 300 ms. The SOA values used were 0 ms and 500 ms, presented randomly across trials. Participants performed both PWI and Stroop in a blocked manner and the order of presentation of the two was counterbalanced across participants. Each picture-word and Stroop stimulus appeared six times with each tone at each SOA, totalling 432 trials. The two tones were presented randomly across trials. Trials were randomised using Mix (Van Casteren & Davis, 2006) with the constraints that the same tone, stimulus type and SOA did not appear on more than three consecutive trials. One unique list per participant was generated.

Procedure and apparatus. The presentation of stimuli and the recording of responses were controlled by Presentation Software (Neurobehavioral Systems, Albany, CA). The tones were presented via closed headphones and vocal responses were measured with a voice key. The button box was designed using Force Sensitive Resistors in order to make the button presses silent. Participants were instructed to rest the outer side of their left and right hands on the silent button box and to apply slight pressure with their index fingers on the buttons in order to make a response to the tones (left button - low tone; right button - high tone). Moreover, they were instructed to name the pictures and to try to ignore the distractor words, or to name the ink colour of the colour words. We emphasised that they should respond to the tone first, and should try to be fast and

accurate in performing both tasks. Next, they were familiarised with the tones. A practice block of six trials of the paradigm they would see next (with different materials from the experimental ones), with the two SOAs presented randomly, preceded each experimental block.

At the 0-ms SOA, a trial began with the visual stimuli and the tone being presented simultaneously. At the 500-ms SOA, the tone was presented first, followed by the visual stimuli. The visual stimuli always remained on the screen for 1250 ms, followed by a black screen for 1750 ms. RTs were measured from stimulus onset (from tone stimuli onset for manual responses and from Stroop/PWI stimuli onset for vocal responses) and lasted until the end of the trial. The whole experimental session lasted approximately 30 minutes.

Analysis. Each trial had a manual response to the tone and a vocal response to the visual stimulus. First, all trials for which a vocal response was given before a manual response were discarded. Trials with manual RTs shorter than 100 ms and trials in which the voice key was triggered by a sound which was not the participant's response or with vocal RTs shorter than 200 ms were discarded. Trials with incorrect tone classification were coded as errors and subsequently excluded from the RT analyses. Additionally, vocal responses which contained a disfluency, a wrong pronunciation of the word, or a wrong response word were also coded as errors and subsequently excluded. RTs were submitted to by-participant (F_1) repeated measures ANOVAs for each task separately (manual and vocal), with stimulus type (congruent, incongruent and neutral) and SOA (0 and 500 ms) as within-participant and within-item variables, and paradigm (PWI and Stroop) as within-participant and between-item variable (note that with only three items, by-item analyses of the naming RTs are not informative). Errors were submitted to logistic regression analyses with stimulus type, SOA, and paradigm as predictors. For completeness, 95% confidence intervals (calculated from the variance over participants) and Cohen's d (calculated as the difference between two conditions divided by the squared root of their averaged variance, see Cumming, 2012) are provided in addition for the relevant effects (of stimulus type) of the naming responses. We compared both congruent and neutral stimuli to incongruent stimuli and refer to them below as Stroop-interference effects for the Stroop paradigm and as Stroop-like interference effects for the PWI paradigm.

5.2.2 Results

Figure 5.2 shows the RTs for the manual (Task 1) and vocal (Task 2) responses as a function of SOA and stimulus type for both the colour-word Stroop and the PWI paradigms.

Manual responses. Table 5.2 presents the error rates for the manual responses as a function of SOA and stimulus type. No predictor was significant in the logistic regression model, all ps $> .05$. For the RTs, there was a marginally significant main effect of stimulus type, $F_1(2,30) = 2.97$, $p = .066$. All remaining comparisons were not significant, all Fs

< 1.

Vocal responses. Table 5.2 also presents the error rates for the vocal naming responses as a function of SOA and stimulus type. Only stimulus type was a significant predictor in the logistic regression model. The log-odds of an incorrect response in the incongruent condition were 5.38 times higher than in the congruent condition, β *coefficient* = 1.68, *S.E.* = 0.42, *Wald Z* = -4.02, $p < .001$; and 6.24 times higher than in the neutral condition, β *coefficient* = 1.83, *S.E.* = 0.44, *Wald Z* = 4.10, $p < .001$. For the RTs, there was no main effect of paradigm, $F_1(1,15) < 1$, indicating that overall performance was similar in both Stroop and PWI paradigms. SOA and paradigm did not interact, $F_1(1,15) < 1$. There was a main effect of SOA, $F_1(1,15) = 231.6$, $p < .001$; and of stimulus type, $F_1(2,30) = 51.66$, $p < .001$. Crucially, stimulus type and SOA did not interact, $F_1(2,30) < 1$, indicating that the magnitude of the interference effects was similar for both SOAs, that is, they were additive with SOA. Stimulus type and paradigm interacted, $F_1(2,30) = 7.46$, $p = .002$, indicating that the interference effects for the Stroop paradigm were larger than the Stroop-like effects in PWI. Importantly, the Stroop-like effects for the PWI task were significant, incongruent vs. congruent, $t_1(15) = 5.50$, $p < .001$, 95%CI [55, 128], $d = .17$; incongruent vs. neutral, $t_1(15) = 5.53$, $p < .001$, 95%CI [55, 126], $d = .15$; and so were the Stroop effects, incongruent vs. congruent, $t_1(15) = 9.76$, $p < .001$, 95%CI [113, 175], $d = .33$; incongruent vs. neutral, $t_1(15) = 9.42$, $p < .001$, 95%CI [114, 181], $d = .31$. The three-way interaction between stimulus type, SOA and paradigm was not significant, $F_1(2,30) < 1$.

Table 5.2: Error rates (%) for the manual (Task 1) and vocal (Task 2) responses as a function of SOA, stimulus type, and paradigm in Experiment 1. SOA = stimulus onset asynchrony. PWI = picture-word interference.

	Manual				Vocal			
SOA (ms)	0		500		0		500	
Paradigm	Stroop	PWI	Stroop	PWI	Stroop	PWI	Stroop	PWI
Stimulus type								
Congruent	4.7	4.6	2.7	3.1	0.6	1.3	1.1	0.6
Incongruent	5.4	6.0	2.4	1.1	6.3	6.5	5.7	4.8
Neutral	7.2	5.9	3.2	3.7	0.9	1.1	0.9	0.6

5.2.3 Discussion

The results of Experiment 1 are clear: Additive effects of SOA and stimulus type were obtained in naming responses for both the Stroop and PWI paradigms. Overall performance was similar in both Stroop and PWI paradigms. The additive effects of SOA and stimulus type in the Stroop task on Task 2 RTs correspond to what Fagot and Pashler (1992, Experiment 7) observed. Furthermore, the additive effects of SOA and stimulus

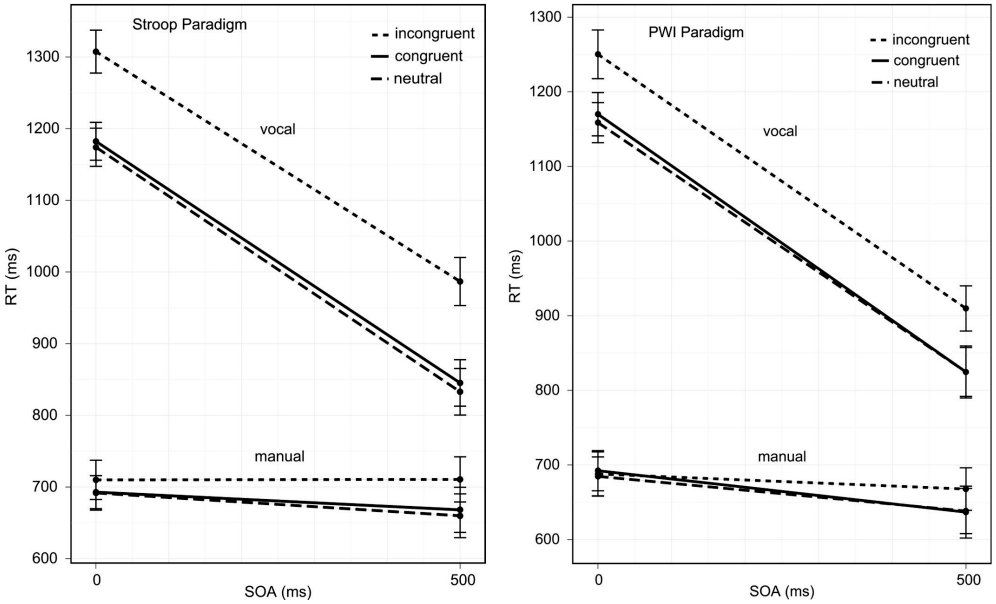

Figure 5.2: Manual (Task 1) and vocal (Task 2) response times (RTs) as a function of SOA and stimulus type for the Stroop paradigm (left) and the PWI paradigm (right) in Experiment 1. Error bars indicate 95% confidence intervals around the mean, calculated from the variance over participants. SOA = stimulus onset asynchrony, PWI = picture-word interference.

type for Task 2 RTs in the PWI task correspond to what Schnur and Martin (2012) and Piai and Roelofs (2013) observed for the semantic interference effect, but it differs from what Dell'Acqua et al. (2007), Ayora et al. (2011), and Van Maanen et al. (2012, Experiment 1) observed. The additivity of the effects of stimulus type and SOA suggests that the effects occurred at the response-selection stage or later (see Figure 5.1B), in disagreement with the proposal of a pre-selection locus by Dell'Acqua et al. Moreover, given that all written words were phonologically regular, the findings do not agree with the account of Kleinman (2013).

A somewhat surprising aspect of the present results is that an effect of stimulus type, albeit marginally significant, was obtained in the Task 1 RTs, especially at 500-ms SOA. Such an effect on Task 1 RTs could indicate that participants' performance in the present experiment differed from performance in the studies of Dell'Acqua et al. (2007) and Schnur and Martin (2012). If so, our pattern of additivity would have no bearing on the discussion regarding the locus of interference effects in dual-task performance. Furthermore, a small stimulus set, as in this experiment, is common for colour-word Stroop, but atypical for PWI experiments. Finally, with the stimulus types used (i.e., incongruent, congruent, and neutral), the Stroop-like effect can be examined, but semantic interference cannot be assessed. However, in the theoretical argumentation of Dell'Acqua et al.

(2007), semantic interference played a central role. To address these issues, Experiment 2 was conducted.

5.3 Experiment 2

Experiment 2 was similar to Experiment 1, except that now only the PWI task was used, with a larger stimulus set and with conditions allowing us to test for semantic interference (semantically related vs. semantically unrelated distractors) and Stroop-like (semantically related vs. congruent distractors) effects in PWI. Table 5.1 presents the experimental parameters of Experiment 2.

If the additivity of effects of SOA and stimulus type in PWI was obtained in Experiment 1 only because of the small stimulus set and the large number of repetitions, a different pattern should be observed in the present experiment. If semantic interference in PWI arises before lexical response-selection, as argued by Dell'Acqua et al. (2007), the effect should be absent at the short SOA and present at the long SOA. However, if the effect arises in or after the response-selection bottleneck, then the effects of SOA and PWI stimulus type should be additive. Moreover, if Stroop-like effects obtained in PWI are similar to the semantic interference effect, a similar pattern should be observed for both effects.

5.3.1 Method

Participants. Twenty-one young adults (2 male, mean age = 20.9, sd = 2.2) participated from the same participant pool and with the same eligibility requirements as for Experiment 1. None of them had participated in the previous experiment.

Materials and design. The design was very similar to Experiment 1, but now only the PWI paradigm was used. Thirty-two pictures of common objects were selected from the same picture gallery as for Experiment 1. This stimulus set was chosen for having yielded reliable semantic interference effects in previous studies (e.g., Piai & Roelofs, 2013, and Chapters 2 and 3). The objects belonged to eight different semantic categories with four objects per category. Each picture was paired with a semantically related distractor, forming the related condition. The unrelated condition was created by re-pairing the pictures with semantically unrelated distractors. In the congruent condition, the pictures were presented with their Dutch basic-level names as distractors. These Dutch distractor words were phonologically regular (Booij, 1995; Nunn, 1998). All distractors belonged to the response set. A list of the materials can be found in Appendix A.6. Each picture-word stimulus appeared once with each tone at each SOA, totalling 384 trials. The two tones were presented randomly across trials. Trials were randomised using Mix (van Casteren & Davis, 2006) with the same constraints as for Experiment 1, with one unique list per participant.

Procedure, apparatus, and analysis. The procedure and apparatus were the same

as in Experiment 1. The same inclusion criteria were used as for Experiment 1. Manual RTs were analysed in the same way as in Experiment 1. Naming RTs were submitted to by-participant (F_1) and by-item (F_2) repeated measures ANOVAs, with stimulus type (congruent, related, and unrelated) and SOA (0 and 500 ms) as within-participant and within-item variables. Errors were submitted to logistic regression analyses with stimulus type and SOA as predictors. Cohen's d and 95% confidence intervals are reported in addition.

5.3.2 Results

Figure 5.3 shows the RTs for the manual (Task 1) and vocal (Task 2) responses as a function of SOA and stimulus type.

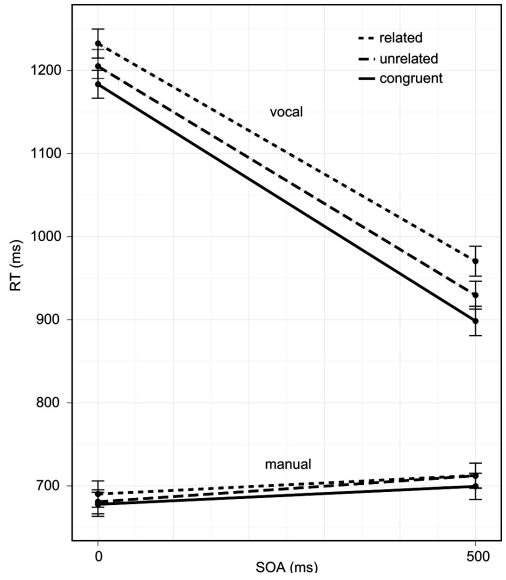

Figure 5.3: Manual (Task 1) and vocal (Task 2) response times (RTs) as a function of SOA and stimulus type for Experiment 2. Error bars indicate 95% confidence intervals around the mean, calculated from the variance over participants. SOA = stimulus onset asynchrony.

Manual responses. Table 5.3 presents the error rates for the manual responses in Experiment 2 as a function of SOA and stimulus type. SOA was a significant predictor in the logistic regression model: The log-odds of an incorrect response at the 0-ms SOA increased by a factor of 1.01, β *coefficient* = -.002, *S.E.* = .001, *Wald Z* = -2.9, $p = .003$. For the RTs, there was a main effect of SOA, $F_1(1,20) = 7.38$, $p = .013$ but no main effect of stimulus type, $F_1(2,40) = 1.07$, $p = .354$. The interaction between SOA and stimulus type was not significant, $F_1 < 1$. These results indicate that, overall, participants were slower in responding to the tones at the 500-ms than at the 0-ms SOA.

Vocal responses. Table 5.3 also presents the error rates for the vocal naming responses in Experiment 2 as a function of SOA and stimulus type. For the error percentages, the log-odds of an incorrect response in the related condition were 3.7 times higher than in the congruent condition, β *coefficient* = -1.30, *S.E.* = .34, *Wald Z* = 3.79, $p < .001$. For the RTs, there was a main effect of SOA, $F_1(1,20) = 265.3$, $p < .001$, $F_2(1,31) = 1185.0$, $p < .001$, and of stimulus type, $F_1(2,40) = 8.29$, $p < .001$, $F_2(2,62) = 29.2$, $p < .001$. Stimulus type and SOA did not interact, Fs < 1, indicating that the distractor effects were similar at both SOAs, i.e., they were additive with SOA. The Stroop-like effect (congruent vs. related) was significant, $t_1(20) = 4.26$, $p < .001$, 95%CI [30,88], $d = .17$, $t_2(31) = 7.51$, $p < .001$, and so was the semantic interference effect (related vs. unrelated), $t_1(20) = 6.06$, $p = .002$, 95%CI [16, 60], $d = .12$, $t_2(31) = 4.26$, $p < .001$.

Table 5.3: Error rates (%) for the manual (Task 1) and vocal (Task 2) responses as a function of SOA and stimulus type in Experiments 2, 3, and 4. SOA = stimulus onset asynchrony.

	Experiment 2				Experiment 3				Experiment 4			
	Manual		Vocal		Manual		Vocal		Manual		Vocal	
SOA (ms)	0	500	0	500	0	500	0	500	0	1000	0	1000
Stimulus type												
Related	3.7	1.6	2.9	4.1	4.1	1.8	2.6	3.2	2.6	1.8	3.9	4.2
Unrelated	4.0	2.0	3.1	1.6	4.4	2.0	1.4	2.2	3.7	1.8	2.3	3.6
Congruent	5.4	1.4	0.8	0.6								

5.3.3 Discussion

Experiment 2 was more similar to that of Dell'Acqua et al. (2007) regarding the stimulus-set size, although we used the congruent condition in addition to the semantically related and unrelated conditions. As in Experiment 1, we observed that the stimulus type effects were additive with SOA for the naming responses, similar to what Schnur and Martin (2012) obtained, but different from Dell'Acqua et al.'s results. The additivity of the effects of stimulus type and SOA suggests that the semantic and Stroop-like interference occurred at the response-selection stage or later, which challenges the proposal of a pre-selection locus by Dell'Acqua et al. Moreover, given that the distractor words were phonologically regular, the findings are not in agreement with the account of Kleinman (2013).

An unexpected aspect of the data is the finding that Task 1 RTs were shorter at the short compared to the long SOA. One possible explanation for this pattern is that participants grouped their responses for Tasks 1 and 2 (e.g., Sanders, 1964, 1988). That is, the Task 1 response is not executed as soon as it is ready, but it is withheld until the Task 2 response is ready. Grouping is, however, unlikely to account for the SOA effect in Task 1 RTs. If participants group their responses, the difference in RTs between Tasks

1 and 2 should be relatively small (i.e., around 100-200 ms, e.g., Miller & Ulrich, 2008; Sanders, 1964). Contrary to this prediction, differences in RTs at the 0-ms SOA were around 500 ms. It cannot be the case that participants prepared the Task 1 response and waited to group it with the Task 2 response, while still obtaining a difference of around 500 ms between the two tasks. Importantly, response grouping does not seem to affect the predictions of a standard bottleneck model with respect to Task 2 RTs (Ulrich & Miller, 2008). That is, the additivity observed in the present experiment should be obtained even if participants grouped their responses.

In sum, we observed additive effects of SOA and stimulus type for the naming responses, contrary to what Dell'Acqua et al. (2007), Ayora et al. (2011), and Van Maanen et al. (2012, Experiment 1) obtained. However, different from these studies, we had a congruent condition in the experiment. Under a strategic bottleneck model (e.g., Meyer & Kieras, 1997a; Roelofs, 2007, 2008a), it is possible that the inclusion of this congruent condition affected participants' strategies. The congruent condition usually elicits shorter RTs than the related and unrelated conditions (e.g., Glaser & Düngelhoff, 1984), increasing the risk for participants to respond to the Task 2 PWI stimulus before responding to the Task 1 tone stimulus, especially at the 0-ms SOA. This could have made participants adopt a more conservative strategy (cf. Meyer & Kieras, 1997a), allowing no overlap between response selection processes, causing the additivity we observed. Similarly, as argued by Van Maanen et al. (2012), the inclusion of congruent distractors may influence the amount of attention that participants allocate to the distractors. To see whether the congruent condition may have caused the difference in results between Dell'Acqua et al. (2007), Ayora et al. (2011), and Van Maanen et al. (2012, Experiment 1) and the present study, Experiment 3 was conducted.

5.4 Experiment 3

Van Maanen et al. (2012) demonstrated that the presence or absence of congruent distractors may affect whether additive or underadditive effects of distractor type and SOA are obtained. With only semantically related and unrelated distractors in an experiment, they observed that the semantic interference effect was underadditive with the SOA effect (their Experiment 1), replicating Dell'Acqua et al. (2007). However, when congruent distractors were added to the experiment (their Experiment 2), the magnitude of the interference effect was similar at the 100 and 800 ms SOAs. To investigate whether the additivity of Task 2 effects with SOA in our Experiment 2 was due to the inclusion of the congruent condition, this condition was omitted from Experiment 3. The rest of the experiment was identical to Experiment 2. Table 5.1 presents the experimental parameters of Experiment 3.

According to Van Maanen et al., we should now obtain underadditive effects of stimulus type and SOA because no congruent distractors appear in the PWI task, different from what we obtained in Experiment 2.

5.4.1 Method

Participants. Nineteen young adult participants (4 male, mean age = 20.5, sd = 2.4) from the same participant pool and with the same eligibility requirements as for Experiments 1 and 2 took part in the experiment. None of them had participated in the previous experiments.

Materials and design. The design was very similar to Experiment 2, except that only the related and unrelated conditions were used. Each picture-word stimulus appeared once with each tone at each SOA, totalling 256 trials. The two tones were presented randomly across trials. Trials were randomised using Mix (van Casteren & Davis, 2006) with the same constraints as for Experiment 1, with one unique list per participant.

Procedure, apparatus, and analysis. The procedure and apparatus were the same as for the previous experiments. The same inclusion criteria were used as for Experiments 1 and 2. Errors and manual and vocal RTs were analysed in the same way as in Experiment 2, with stimulus type including only the related and unrelated conditions.

5.4.2 Results

Figure 5.4 shows the RTs for the manual (Task 1) and vocal (Task 2) responses as a function of SOA and stimulus type.

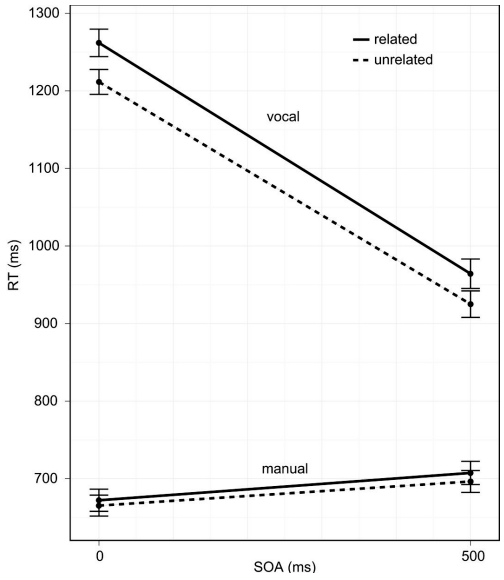

Figure 5.4: Manual (Task 1) and vocal (Task 2) response times (RTs) as a function of SOA and stimulus type for Experiment 3. Error bars indicate 95% confidence intervals around the mean, calculated from the variance over participants. SOA = stimulus onset asynchrony.

Manual responses. Table 5.3 presents the error rates for the manual task as a function of SOA and stimulus type. SOA was a significant predictor in the logistic regression model: The log-odds of an incorrect response at the SOA 0 ms increased by a factor of 1.01, β *coefficient* = -.002, *S.E.* = .000, *Wald Z* = -4.1, $p < .001$. For the RTs, there was a main effect of SOA, $F_1(1,18) = 12.7$, $p = .002$, and a marginally significant main effect of stimulus type, $F_1(1,18) = 3.4$, $p = .080$. The interaction between SOA and stimulus type was not significant, $F_1 < 1$. Thus, overall responses to the tone were longer at the 500-ms SOA than at the 0-ms SOA.

Vocal responses. Table 5.3 also presents the error rates for the vocal naming responses as a function of SOA and stimulus type. For the errors, the log-odds of an incorrect response in the related condition increased by a factor of 1.64 relative to the unrelated condition, β *coefficient* = .492, *S.E.* = .211, *Wald Z* = 2.33, $p = .019$. For the RTs, there was a main effect of SOA, $F_1(1,18) = 172.7$, $p < .001$, $F_2(1,31) = 1038.0$, $p < .001$, and of stimulus type, $F_1(1,18) = 81.11$, $p < .001$, 95%CI [31, 54], $d = .14$, $F_2(1,31) = 23.7$, $p < .001$. Stimulus type and SOA did not interact, Fs < 1. Altogether, these results indicate that the semantic interference effect was of similar magnitude across SOAs, that is, additive with SOA.

5.4.3 Discussion

In this experiment, we used the semantically related and unrelated conditions only, exactly as Dell'Acqua et al. (2007) did. Yet, we still observed additive effects of SOA and stimulus type in the naming responses, replicating the pattern of results of Schnur and Martin (2012) and Piai and Roelofs (2013). Thus we did not replicate Dell'Acqua et al. (2007), Ayora et al. (2011), and Van Maanen et al. (2012, Experiment 1), who observed underadditive effects of SOA and stimulus type (with semantically related and unrelated distractors only). However, another difference between Dell'Acqua et al.'s (2007) design and the present experiments concerns the SOAs used. Whereas Dell'Acqua et al. used SOAs of 100, 350, and 1000 ms, we used SOAs of 0 and 500 ms. This difference in SOAs could be important for the following reason. The mean RTs for the manual tone-discrimination task (Task 1) were around 600-700 ms, both in the experiment of Dell'Acqua et al. and in our first three experiments. This means that the two SOA values that we used are smaller than the mean RTs of Task 1, whereas this does not hold for Dell'Acqua et al., who had one SOA (1000 ms) larger than the Task 1 mean RTs. Thus in our case, at both SOAs, Task 2 stimuli were presented, on average, before participants had completed Task 1. The likelihood of Task 2 responses preceding Task 1 responses is higher in this case than in Dell'Acqua et al.'s case, which had an SOA longer than Task 1 mean RTs. This property of our design could have influenced participants' strategies to avoid out of order Task 2 responses (i.e., making them more conservative, cf. Meyer & Kieras, 1997a), yielding the observed patterns of additivity.

In Experiment 4, we therefore used SOAs of 0 ms and 1000 ms (see also Ayora *et al.*, 2011). If the additivity observed in our first three experiments was caused by the

fact that the long SOA was always shorter than the average manual RTs, the effect of SOA and stimulus type should now be underadditive.

5.5 Experiment 4

This experiment was very similar to Experiment 3, except that the SOA of 500 ms was replaced by an SOA of 1000 ms. Table 5.1 presents the experimental parameters of Experiment 4.

5.5.1 Method

Participants. Sixteen young adults (2 male, mean age = 22.5, $sd = 3.14$) from the same participant pool and with the same eligibility requirements as for the other experiments participated in the experiment.

Materials and design. The design was very similar to Experiment 3, except that now we used the SOAs of 0 ms and 1000 ms between the tone stimulus and the PWI stimulus. Each picture-word stimulus appeared once with each tone at each SOA, totalling 256 trials. The two tones were presented randomly across trials. Trials were randomised in a fashion similar to Experiment 1.

Procedure, apparatus, and analysis. The procedure and apparatus were the same as for the other experiments. The same inclusion criteria were used as for the other experiments. The same analyses were conducted as for Experiment 3.

5.5.2 Results

Figure 5.5 shows the RTs for the manual (Task 1) and vocal (Task 2) responses as a function of SOA and stimulus type.

Manual responses. Table 5.3 presents the error rates for the manual responses as a function of SOA and stimulus type for Experiment 4. In the logistic regression model, SOA was a significant predictor: The log-odds of an incorrect response at the SOA 0 ms increased by a factor of 1.01, β *coefficient* = -.001, *S.E.* = .000, *Wald Z* = -2.4, $p = .019$. For the RTs, there was a main effect of SOA, $F_1(1,15) = 30.02$, $p < .001$. The effect of stimulus type was not significant, $F_1 < 1$. SOA and stimulus type did not interact, $F_1(1,15) = 3.31$, $p = .089$.

Vocal responses. Table 5.3 also presents the error rates for the vocal naming responses as a function of SOA and stimulus type for Experiment 4. In the logistic regression model, the log-odds of an incorrect response in the related condition increased by a factor of 1.45 relative to the unrelated condition, β *coefficient* = .373, *S.E.* = .189, *Wald Z* = 1.97, $p = .049$. For the RTs, there was a main effect of SOA, $F_1(1,15) = 231.6$, $p < .001$, $F_2(1,31) = 2438.0$, $p < .001$, and of stimulus type, $F_1(1,15) = 10.8$, $p = .005$, 95%CI [3,

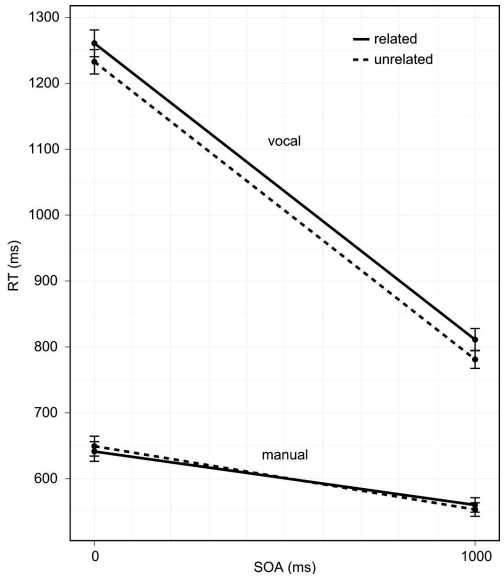

Figure 5.5: Manual (Task 1) and vocal (Task 2) response times (RTs) as a function of SOA and stimulus type for Experiment 4. Error bars indicate 95% confidence intervals around the mean, calculated from the variance over participants. SOA = stimulus onset asynchrony.

55], $d = .07$, $F_2(1,31) = 6.4$, $p = .017$. Stimulus type and SOA did not interact, Fs < 1. Altogether, these results indicate that the magnitude of the semantic interference effect was similar at both SOAs. That is, the semantic interference effect was additive with the SOA effect.

5.5.3 Discussion

In Experiment 4, SOAs of 0 and 1000 ms were used. The difference between the short and long SOAs is similar to the difference between the short and long SOAs of 100 and 1000 ms used by Dell'Acqua et al. (2007). Using a long SOA of 1000 ms in our experiment, however, did not affect the pattern of results. As in the first three experiments, the effects of SOA and stimulus type were additive in the naming latencies. However, different from the earlier experiments, we now obtained an increase of Task 1 RTs at the short SOA. That is, the tone discrimination RTs were longer at the short (0 ms) than at the long (1000 ms) SOA, whereas no such increase was obtained for the short (0 ms) and long (500 ms) SOAs in Experiments 1 to 3. This indicates that the additivity of SOA and stimulus type effects is independent of whether a short-SOA increase is obtained in the Task 1 RTs (which was the case in the present experiment) or not (which was the case in the first three experiments).

Experiments 1 to 4 showed a pattern of additivity of stimulus type and SOA

effects in naming latencies, arguing against Dell'Acqua et al.'s (2007) interpretation that the semantic interference effect emerges before lexical response-selection. There is, however, another aspect in the design used by Dell'Acqua et al. (2007) that is different from ours: Dell'Acqua et al. used two relatively short SOAs (100 and 350 ms) and one long SOA, whereas so far we have constantly used the same proportion of short and long SOAs in our experiments. This difference could be important given a demonstration by Miller and colleagues (Miller *et al.*, 2009) that, as the proportion of short SOA increases, participants tend to shift away from serial processing towards a more parallel mode of processing. However, Miller et al. used two manual tasks rather than manual responding and naming, so their observations need not generalise to our experimental situation. By encountering twice as many trials with short than long SOAs, the participants of Dell'Acqua et al. could have had the tendency to engage in more parallel processing, allowing response selection in picture naming to temporally overlap with response selection for tone discrimination. Independent evidence that response-selection processes may overlap comes from previous PRP studies showing underadditive effects of Task 2 response-selection manipulations and SOA (e.g., Karlin & Kestenbaum, 1968; Schumacher *et al.*, 1999; Thomson *et al.*, 2010). If the participants of Dell'Acqua et al. selected the picture name in parallel with the tone-discrimination response on a large number of trials, the underadditivity of semantic interference and SOA effects could be explained by the absorption of the interference effect into slack. Note that this account assumes that the semantic interference effect arises during response selection and that the response-selection bottleneck is strategically imposed rather than structural and immutable.

5.6 Experiment 5

In this experiment, which was very similar to Experiment 4, we used the SOAs of 0 and 1000 ms, but now we varied the proportion of SOAs such that the short SOA was presented more than twice as often as the long SOA. Importantly, we increased the number of 0-ms SOA trials rather than adding a different short SOA (e.g., 350 ms) to keep the experiment comparable with the previous ones (which also had only two SOA values). Adding another SOA value would have changed not only the proportion of short- and long-SOA trials, but also the number of SOA values used, making it more difficult to compare Experiment 5 with Experiments 1-4. In our Experiments 1-4 and Piai and Roelofs (2013), we observed additive effects of SOA and distractor type with two SOA values and the same proportion of short- and long-SOA trials. Using more short- than long-SOA trials, Dell'Acqua et al. obtained underadditive effects of SOA and distractor type, whereas Schnur and Martin obtained additive effects (as Kleinman and Van Maanen et al. did in some experiments). Experiment 5 examined whether (with our materials, design, and participant pool) different proportions of short- and long-SOA trials yield additive effects of SOA and distractor type (Schnur & Martin) or underadditive effects (Dell'Acqua *et al.*). If additive effects are obtained (replicating Schnur & Martin), this would indicate

that this pattern of effects occurs regardless of whether the proportions of short- and long-SOA trials are the same (Experiments 1-4) or different (Experiment 5). Instead, if participants shift towards more parallel processing due to the higher probability of short than long SOAs (Miller *et al.*, 2009), we may observe underadditive effects of stimulus type and SOA (as Dell'Acqua et al. did), since the semantic interference would be resolved in parallel with Task 1 processing. Table 5.1 presents the experimental parameters of Experiment 5.

5.6.1 Method

Participants. Sixteen young adults (all female, mean age = 19.4, $sd = 1.6$) from the same participant pool and with the same eligibility requirements as for the other experiments participated.

Materials and design. The SOAs of 0 ms and 1000 ms were used. The distractors were either related or unrelated to the picture. Each picture-word stimulus was presented five times in the experiment, totalling 320 trials. The two tones were presented randomly across trials, but equally often with each stimulus type. The 1000-ms SOA was used in 100 trials (50 from the related and 50 from the unrelated conditions) and the 0-ms SOA was used in 220 trials (110 trials from each stimulus type condition). Trials were randomised using Mix (van Casteren & Davis, 2006) with one unique list per participant.

Procedure, apparatus, and analysis. The procedure and apparatus were the same as for the other experiments. The same inclusion criteria were used as for the other experiments. The same analyses were conducted as for Experiment 3.

5.6.2 Results

Figure 5.6 shows the RTs for the manual (Task 1) and vocal (Task 2) responses as a function of SOA and stimulus type.

Manual responses. Table 5.4 presents the error rates for the manual responses as a function of SOA and stimulus type for Experiment 5. SOA was a significant predictor in the logistic regression model: The log-odds of an incorrect response at the 0-ms SOA increased by a factor of 1.01, β *coefficient* = -.001, *S.E.* = .000, *Wald Z* = -5.1, $p < .001$. For the RTs, there was a main effect of SOA, $F_1(1,15) = 17.9$, $p < .001$. The effect of stimulus type was not significant, $F_1(1,15) = 1.8$, $p = .240$. SOA and stimulus type did not interact, $F_1 < 1$.

Vocal responses. Table 5.4 also presents the error rates for the vocal naming responses as a function of SOA and stimulus type for Experiment 5. No predictor was significant in the logistic regression model, all ps $> .08$. For the RTs, there was a main effect of SOA, $F_1(1,15) = 155.0$, $p < .001$, $F_2(1,31) = 2406.0$, $p < .001$, and of stimulus type, $F_1(1,15) = 19.2$, $p < .001$, 95%CI [14, 55], $d = .09$, $F_2(1,31) = 25.9$, $p < .001$. Stimulus type and

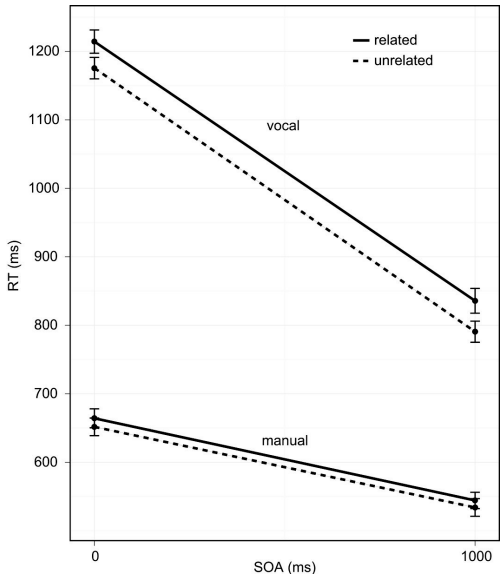

Figure 5.6: Manual (Task 1) and vocal (Task 2) response times (RTs) as a function of SOA and stimulus type for Experiment 5. Error bars indicate 95% confidence intervals around the mean, calculated from the variance over participants. SOA = stimulus onset asynchrony.

SOA did not interact, Fs < 1. These results demonstrate that a semantic interference effect was obtained, which was of similar magnitude at long and short SOAs.

Table 5.4: Error rates (%) for the manual (Task 1) and vocal (Task 2) responses as a function of SOA and stimulus type in Experiments 5 and 6. SOA = stimulus onset asynchrony.

	Experiment 5				Experiment 6			
	Manual		Vocal		Manual		Vocal	
SOA (ms)	0	1000	0	1000	0	1000	0	1000
Stimulus type								
Related	5.2	1.4	3.2	1.3	3.4	4.2	2.4	3.0
Unrelated	5.3	1.9	2.1	2.2	5.9	4.4	1.7	2.8

5.6.3 Discussion

In this experiment, we varied the proportion of short SOAs relative to the long SOAs. Following Miller et al. (2009), we hypothesised that the underadditivity obtained by Dell'Acqua et al. (2007) might be due to their use of two short SOA values (100 and 350

ms), making participants engage in parallel processing, (partly) resolving semantic interference concurrently with Task 1 processing. However, even with the inclusion of twice as many short SOA trials than long SOA trials, we still obtained additivity of semantic interference and SOA effects on the naming responses, in line with our Experiments 1 to 4, Schnur and Martin (2012), and Piai and Roelofs (2013), but different from Dell'Acqua et al. (2007). Thus the greater relative number of trials with short than long SOAs (Experiment 5) did not influence the pattern of additivity of SOA and stimulus type effects in our study, as the results were comparable with the previous experiments, which had the same number of short- and long-SOA trials. Ayora et al. (2011) also had the same number of short- and long-SOA trials, and they obtained underadditivity of semantic interference and SOA effects, similar to Dell'Acqua et al., who had relatively more short SOA trials than long SOA trials.

In Experiments 1 to 5, the distractor words were phonologically regular, which should yield underadditive effects of distractor type and SOA, according to Kleinman (2013). Nevertheless, in all our experiments, we obtained additive effects, in disagreement with the account of Kleinman.

There are, however, yet other differences between our experiments and the experiment of Dell'Acqua et al. (2007). These differences include the number of tones presented to participants (two in our case vs. three in their study), the pitch and duration of the tones, the number of SOAs used and their values (two SOAs in our case vs. three SOAs of 100, 350, and 1000 ms in Dell'Acqua et al.'s study), and the fact that our distractors were members of the response set whereas theirs were not. Perhaps, some of these differences may have affected strategic scheduling of processes, yielding the discrepancy in results. Therefore, Experiment 6 is a final attempt to replicate Dell'Acqua et al., Ayora et al. (2011), and Van Maanen et al. (2012, Experiment 1).

5.7 Experiment 6

Experiment 6 is our final attempt to obtain the pattern of underadditivity observed by Dell'Acqua et al. (2007) and later replications. In line with Experiments 1 to 5 and Ayora et al. (2011), we only used two SOAs. To approach the experiments of Dell'Acqua et al. and Ayora et al. as closely as possible, we used an SOA of 100 ms rather than the 0 ms used in Experiments 1 to 5. Since Dell'Acqua et al. did not report their materials, we used the materials reported in Ayora et al. translated into Dutch. This means that our design was as similar as possible to the design of Ayora et al. Table 5.1 presents the experimental parameters of Experiment 6.

5.7.1 Method

Participants. Sixteen young adult participants (all female, mean age = 18.56, sd = 1.67) from the same participant pool and with the same eligibility requirements as for the other experiments took part in the experiment.

Materials and design. We used the 35 picture names of Ayora et al. (2011), with the corresponding pictures taken from the database of the Max Planck Institute for Psycholinguistics, Nijmegen, or from our own database. Our distractor words (semantically related or unrelated to the pictures) were Dutch translations of the words reported by Ayora et al., so the distractors were not members of the response set. Since their distractor words were matched for frequency and length, we acquired frequency counts for our Dutch distractors from CELEX (Baayen, Piepenbrock, & van Rijn, 1993) and tested for differences in frequency and length between the semantically related and unrelated distractors, $ts < 1$. Each picture-word stimulus appeared twice at each SOA, totalling 280 trials. The second presentation of the stimuli followed the first presentation of all stimuli. Trials were randomised using Mix (van Casteren & Davis, 2006) using the same constraints as for Experiment 1, with one unique list per participant. As indicated, the SOAs of 100 ms and 1000 ms were used. The tones were pure tones of 300, 600, and 1200 Hz, lasting 50 ms, following Dell'Acqua et al. (2007) and Ayora et al. The three tones were combined randomly with the PWI stimuli and were presented at random across trials, but equally often with each stimulus type and at each SOA.

Procedure, apparatus, and analysis. The same apparatus was used as for the other experiments. The aspects of the procedure that differed with respect to the previous experiments are mentioned here. Participants were instructed to rest two fingers of their choice from one hand and one finger from the other hand on the buttons (left button - low tone; middle button - medium tone; right button - high tone). As in Dell'Acqua et al. (2007) and Ayora et al., each trial began with the presentation of a fixation cross for 1000 ms, followed by a black screen for 800 ms, followed by one of the three tones. At an SOA of 100 or 1000 ms, the visual stimulus was displayed. The same inclusion criteria were used as for the other experiments. The same analyses were conducted as for Experiment 3.

5.7.2 Results

Figure 5.7 shows the RTs for the manual (Task 1) and vocal (Task 2) responses as a function of SOA and stimulus type.

Manual responses. Table 5.4 presents the error rates for the manual responses as a function of SOA and stimulus type for Experiment 6. The logistic regression model showed that the log-odds of an incorrect response for unrelated stimuli increased by a factor of 1.43 relative to related stimuli, β *coefficient* = .359, *S.E.* = .164, *Wald* $Z = 2.2$, $p = .029$. For the RTs, there was a main effect of SOA, $F_1(1,15) = 32.6$, $p < .001$, and a main effect of stimulus type, $F_1(1,15) = 25.6$, $p < .001$. The interaction between SOA and stimulus type was not significant, $F_1(1,15) = 1.9$, $p = .190$.

Vocal responses. Table 5.4 also presents the error rates for the vocal naming responses as a function of SOA and stimulus type for Experiment 6. No predictors were significant in the logistic regression model, all $ps > .100$. For the RTs, there was a main effect of

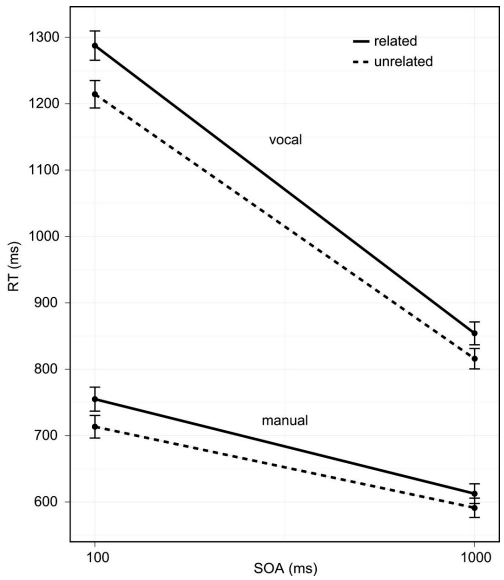

Figure 5.7: Manual (Task 1) and vocal (Task 2) response times (RTs) as a function of SOA and stimulus type for Experiment 6. Error bars indicate 95% confidence intervals around the mean, calculated from the variance over participants. SOA = stimulus onset asynchrony.

SOA, $F_1(1,15) = 154.0$, $p < .001$, $F_2(1,34) = 1563.7$, $p < .001$, and of stimulus type, $F_1(1,15) = 39.8$, $p < .001$, 95%CI [32, 72], $d = .13$, $F_2(1,34) = 12.4$, $p = .001$. Stimulus type and SOA did not interact, $F_1(1,15) = 3.03$, $p = .102$, $F_2(1,34) = 2.8$, $p = .104$. These results indicate that a semantic interference effect was present in the data, with similar magnitude across SOAs, that is, the effect was additive with SOA.

5.7.3 Discussion

The results of Experiment 6, which was conducted with the materials of Ayora et al. (2011) translated into Dutch, showed additivity of the effects of stimulus type and SOA in the naming latencies, similar to Schnur and Martin (2012), Piai and Roelofs (2013), and our Experiments 1 to 5, but different from the results of Dell'Acqua et al. (2007), Ayora et al. (2011), and Van Maanen et al. (2012, Experiment 1). Thus, the differences in SOA values, in the number of tones, their pitch and duration, and in response-set membership do not seem to be factors modulating the patterns of additivity we have obtained with our experiments thus far. Importantly, as Experiment 6 shows, the additivity observed in our experiments using the short SOA of 0 ms (Experiments 1-5) is also observed when the short SOA is 100 ms, which was the SOA used by Dell'Acqua et al., Ayora et al., and Van Maanen et al.

A main effect of stimulus type was found at both SOAs in the manual RTs.

The effect of stimulus type on manual RTs at the 1000 ms SOA may seem impossible at first sight since participants responded, on average, within 605 ms. So at an SOA of 1000 ms, they cannot have seen the Task 2 stimulus before responding in Task 1 and, therefore, no effects of a manipulation in Task 2 should be present in Task 1 responses. However, all the analyses reported here were performed on untrimmed data (cf. Miller, 1991; Ulrich & Miller, 1994). This means that, even though mean RTs for the manual task are around 605 ms, there are still many responses included in the analyses that were given after participants had seen Task 2 stimuli, that is, RTs larger than 1000 ms. To test this explanation, we left out of the analyses all manual RTs longer than 1000 ms and tested the effect of stimulus type at the 1000 ms SOA. This test showed that, once we only included the RTs of trials for which we know for sure participants did not see the Task 2 stimulus before responding, there was no longer an effect of stimulus type on Task 1 RTs, $t(15) = 1.53$, $p = .148$.

5.8 General Discussion

As outlined previously, the locus of the semantic interference effect in picture naming plays a pivotal role in guiding theories of language production (e.g., Dell'Acqua *et al.*, 2007; Levelt *et al.*, 1999; Miozzo & Caramazza, 2003; Roelofs, 1992). Based on underadditive effects of SOA and stimulus type on picture naming RTs in dual-task performance, Dell'Acqua et al. (2007) and Ayora et al. (2011) argued for a pre-selection locus of the semantic interference effect. However, in three experiments, Schnur and Martin (2012) and Piai and Roelofs (2013) obtained additive effects of SOA and stimulus type, arguing in favour of a locus at lexical response-selection or a later stage. On the basis of the experiments available in the literature, the pattern of results is inconclusive as three experiments show underadditivity of semantic and SOA effects (Ayora *et al.*, Dell'Acqua *et al.*, Van Maanen *et al.*) and three experiments show additivity of the effects (Schnur & Martin, and Piai & Roelofs). Given the importance of empirical replications to determine the robustness of an experimental finding (e.g., Cumming, 2008, 2012; Cumming & Maillardet, 2006; Fisher, 1966; Tukey, 1969), the present study aimed at manipulating the experimental design in various ways to examine which pattern of SOA and semantic effects in PWI under the PRP procedure is most robustly obtained.

The present results can be summarised as follows. The additivity of Stroop and SOA effects reported by Fagot and Pashler (1992, Experiment 7) was replicable and robust. Furthermore, in all six experiments, the magnitude of stimulus type effects was independent of SOA, and the additivity with SOA was obtained even though the distractors were phonologically regular (cf. Kleinman, 2013). This held regardless of the exact tasks (PWI, colour-word Stroop), materials (new, translations of Ayora et al.), stimulus types (related, unrelated, Stroop-like congruent, neutral), number of tones (two or three), and (proportion of) SOAs (0, 100, 500, 1000 ms) used[2]. Moreover, the additivity

[2]The number of participants varied across experiments, but there was no profound reason for this. We

of the effects of SOA and stimulus type was obtained regardless of whether there was an SOA or a stimulus-type effect in the Task 1 RTs. Thus, with manual responding and naming, additivity of stimulus type and SOA effects appears to be a persistent pattern, replicable across variations of the experimental procedure. In contrast, the results of Van Maanen et al. (2012) suggest that underadditive effects of stimulus type and SOA are less robustly obtained. They observed that the underadditivity may disappear when congruent PWI stimuli are included in an experiment (although even this does not always happen, see our Experiment 3). The additive effects of distractor type and SOA provide evidence for a locus at response selection or later of the semantic and Stroop-like interference effects and a response-selection bottleneck in dual-task performance (see Figure 5.1B), whereby the response-selection bottleneck is either structural (Pashler, 1984, 1994) or strategic (Meyer & Kieras, 1997a; Piai *et al.*, 2011; Roelofs, 2007, 2008a; Roelofs & Piai, 2011). We further discuss this below.

Regarding the manual RTs, in Experiments 2 and 3, with SOAs of 0 and 500 ms, participants responded more quickly to the tones at the 0-ms SOA than at the 500-ms SOA. However, this pattern reversed in Experiments 4, 5 and 6, where 1000 ms was used for the long SOA: Responses were slower at the short SOAs (0 and 100 ms) than at the long SOA. We argued that this pattern of findings could not be explained by response grouping because the temporal lag between Task 2 and Task 1 responses is too long, i.e., 500 ms on average (cf. Miller & Ulrich, 2008). Importantly, whatever the pattern of results for Task 1 was, in all cases we observed additive effects of stimulus type and SOA for Task 2.

5.8.1 The nature of the processing bottleneck

The apparent malleability of the semantic interference effect (absent at short SOAs in the experiments of Dell'Acqua et al., 2007, Ayora et al., 2011, and Van Maanen et al., 2012, Experiment 1, and present in the experiments of Schnur & Martin, 2012, Piai & Roelofs, 2013, and in the experiments reported here) is difficult to reconcile with an immutable response-selection bottleneck in dual-task performance, as assumed by Dell'Acqua et al. Note that discrepant results emerging from dual-task investigations are not restricted to the present discussion. For example, the effect of practice on the magnitude of the dual-task interference is also different across studies (e.g., Karlin & Kestenbaum, 1968; Ruthruff *et al.*, 2003; Schumacher *et al.*, 2001; Van Selst & Jolicoeur, 1997; Van Selst *et al.*, 1999). These and other findings challenge the assumption of a structural response-

planned to test 16 participants for Experiment 1. Experiment 2 addresses a discrepancy in the literature, hence we increased the planned number of participants to 20. Accidentally, our research assistant ran 21 participants instead. We opted for not excluding any participant, and this is why we report the data for N = 21. For Experiment 3, again we aimed for 20 participants, but we only managed to collect 19 participants before the beginning of the exams period. After two similar experiments (Experiments 2 and 3) replicating the same results, i.e., showing additivity of effects for nearly all 40 participants analysed, we assumed that the effect was powerful and consistent enough, so we did not need to increase statistical power by having many participants, hence we went back to 16 participants.

selection bottleneck in dual-task performance (e.g., Hübner & Lehle, 2007; Israel & Cohen, 2011; Karlin & Kestenbaum, 1968; Lehle & Hübner, 2009; Leonhard & Ulrich, 2011; Meyer & Kieras, 1997a; Miller *et al.*, 2009; Navon & Miller, 2002; Pannebakker *et al.*, 2011; Schumacher *et al.*, 1999, 2001; Schvaneveldt, 1969; Szameitat *et al.*, 2002, 2006; Tombu & Jolicoeur, 2003). Although under the strategic bottleneck account (Meyer & Kieras, 1997a; Piai *et al.*, 2011; Roelofs, 2007, 2008a; Roelofs & Piai, 2011), a response-selection bottleneck is optional rather than obligatory (i.e., response selection in Tasks 1 and 2 may, in principle, occur in parallel), the present findings suggest that participants seem to have a very strong preference for not overlapping response-selection processes in dual-task performance.

As mentioned previously, a powerful third alternative account of dual-task performance is that the bottleneck is not structural or strategic but rather arises from central capacity sharing (e.g., Tombu & Jolicoeur, 2003). The capacity sharing account assumes that dual-task interference occurs because response selection requires central capacity in order to proceed. If all capacity is first allocated to response selection in tone discrimination (Task 1) and then to response selection in PWI (Task 2), then the capacity sharing account would mimic the structural response-selection bottleneck account of Dell'Acqua et al. (2007). However, if capacity is divided between Tasks 1 and 2, response selection processes may overlap, just as may occur under the strategic bottleneck account. If capacity is shared between tasks, Task 1 RTs will be longer than when capacity is not shared. Thus, central capacity sharing may explain why sometimes Task 1 RT increases as SOA decreases, as observed in our Experiments 4-6 and in the experiments of Schnur and Martin (2012). This suggests that participant groups may differ in how central capacity is divided between the response selection stages in the two tasks (i.e., we obtained SOA effects on RT1 in some but not all of our experiments). However, the capacity-sharing account cannot explain the opposing data patterns in the literature (i.e., why the semantic interference effect is absent at short SOAs in the experiments of Dell'Acqua et al., 2007, Ayora et al., 2011, and Van Maanen et al., 2012, Experiment 1, and present in the experiments of Schnur & Martin, 2012, Piai & Roelofs, 2013, and in the experiments reported here). Tombu and Jolicoeur (2003) demonstrated mathematically that if response selection requires central capacity, additive effects are predicted for experimental manipulations of Task 2 response selection and SOA, regardless of the division of capacity between tasks.

To recapitulate, structural and strategic bottleneck as well as central capacity sharing models can all explain the additive effects of stimulus type and SOA obtained in the present experiments and by Schnur and Martin (2012) and Piai and Roelofs (2013). However, only a strategic bottleneck account can accommodate the opposing patterns in the literature (i.e., the underadditive effects of Dell'Acqua et al., 2007, Ayora et al., 2011, and Van Maanen et al., 2012, Experiment1). The present findings suggest that participants strongly prefer imposing a response-selection bottleneck (yielding the pervasive additive effects) rather than a post-selection bottleneck (yielding the less-pervasive

underadditive effects).

5.8.2 The skill of word reading

Participants may not only differ in their preferred bottleneck stage (i.e., response-selection vs. post-selection), but also in reading skill. Ruthruff, Allen, Lien, and Grabbe (2008) observed that reading skill may determine whether additive or underadditive effects are obtained in dual-task performance. Their Task 1 involved auditory or visual discrimination with manual responding and Task 2 involved visual lexical decision concerning high- or low-frequency words as well as nonwords. Ruthruff et al. observed that at short SOAs, a frequency effect was present in the Task 2 RTs for participants with poor reading skill, but the effect was absent for good readers. This suggests that good readers allowed for greater temporal overlap between Tasks 1 and 2 than poor readers.

Reading ability may also affect dual-task performance involving picture-word interference. Following the suggestions of Kleinman (2013) concerning phonological regularity (which were challenged by the results of our experiments), it is possible that distractor word processing (but not lexical response-selection) occurs concurrently with response selection in the tone task for good readers, eliminating semantic interference, whereas distractor word processing is delayed and overlaps with lexical response selection for poor readers, yielding semantic interference. Thus, a difference in reading ability may potentially explain the difference in results between Dell'Acqua et al. (2007), Ayora et al. (2011), and Van Maanen et al. (2012, Experiment 1), on the one hand, and those of Schnur and Martin (2012), Piai and Roelofs (2013), and in the experiments reported here, on the other hand.

However, this reading-skill account meets with a number of difficulties. First, given that we tested a great number of participants (all university students), it is unlikely that most of them were poor readers. Moreover, even if most of our participants were poor readers, it is unlikely that our distractor words were read poorly, because these were all highly familiar high-frequency words that were repeated several times during the experiments. Furthermore, Van Maanen et al. (2012) also used Dutch as the language of their experiments, just like the present study. Yet, the results of Van Maanen et al. and our results do not fully agree, contrary to what would have been predicted by Kleinman's (2013) hypothesis regarding the phonological regularity of our stimuli. Most importantly, even if differences in reading ability could account for the differences in effects between studies, such an account would assume that the locus of the semantic interference effect is at the stage of lexical response-selection or later, which is the major conclusion we drew from the results of our experiments. Still, it would seem important for future studies to examine whether differences in reading ability can account for the variability of semantic effects at short SOAs.

5.8.3 The locus of the semantic interference effect

The additivity of the effects of SOA and stimulus type suggests that the semantic interference effect arises after the pre-selection stage of perceptual and conceptual processing (cf. Schnur & Martin, 2012), but it leaves open whether the effect occurs at the response-selection stage (e.g., Roelofs, 1992) or at the post-selection stage, close to articulation onset, as held by the response exclusion hypothesis (e.g., Janssen *et al.*, 2008; Miozzo & Caramazza, 2003). However, it seems that the semantic interference effect can be localised to the response-selection stage by taking effects of phonological relatedness in dual-task performance into account. Whereas picture naming RTs are increased by semantic relatedness (i.e., the semantic interference effect), they are reduced by phonological relatedness (e.g., in naming the picture of a cat, RTs are shorter with distractor *cap* than with *arm*). According to the model proposed in Chapter 2 (Piai *et al.*, 2011; see also Levelt *et al.*, 1999; Roelofs, 1992, 1997, 2003, 2007, 2008a, 2008c), semantic interference arises in lexical response-selection and phonological facilitation arises during the subsequent post-selection stage of word-form encoding. In contrast, according to the response exclusion account (e.g., Janssen *et al.*, 2008; Miozzo & Caramazza, 2003), semantic interference arises at the post-selection stage, during articulatory buffering, when a response to the distractor is excluded from the buffer, whereas effects of phonological relatedness occur also at the post-selection stage, but before rather than during articulatory buffering. Ayora et al. (2011) examined the effect of semantic and phonological relatedness of distractors on picture naming RTs using the PRP procedure and a single group of participants. They obtained underadditive effects of SOA and semantic relatedness but additive effects of SOA and phonological relatedness. Under the strategic bottleneck account of Chapter 2 (Piai *et al.*, 2011), participants may or may not allow overlap between response selection in the tone and picture naming tasks. This implies that phonological effects should always be additive with SOA, as observed by Ayora et al. (2011), whereas semantic effects are additive (Schnur & Martin, 2012; Piai & Roelofs, 2013; present experiments) or underadditive (Dell'Acqua *et al.*, 2007; Ayora *et al.*, 2011; Van Maanen *et al.*, 2012, Experiment 1) depending on whether overlap of response selection between tasks is allowed or not. In contrast, the response exclusion hypothesis fails to account for these findings.

The additivity of the effects of SOA and phonological relatedness obtained by Ayora et al. (2011) would suggest that the bottleneck is before the onset of phonological encoding (i.e., Ayora et al. assume a lexical response-selection bottleneck). However, according to the response exclusion hypothesis, given that the semantic interference effect arises after phonological encoding, during articulatory buffering, the effects of SOA and semantic relatedness also have to be additive, contrary to what Ayora et al. observed. Similarly, Ferreira and Pashler (2002) presented participants with PWI stimuli (Task 1) followed by tone discrimination (Task 2). They observed that the semantic interference effect from Task 1 propagated into Task 2 RTs whereas the phonological effect did not. The authors interpreted these effects as evidence that lexical response-selection is subject to a central processing bottleneck, whereas phonological encoding is not. According to

the response exclusion account, the semantic interference effect arises after phonological encoding, thus the semantic effect should not propagate into Task 2 RTs, contrary to the empirical findings. To conclude, the present findings, taken together with those of Ayora et al. and Ferreira and Pashler, suggest that semantic interference arises in lexical response-selection, in line with modern psycholinguistic models of spoken word production (e.g., Abdel Rahman & Melinger, 2009b; Damian & Martin, 1999; Levelt *et al.*, 1999; Roelofs, 1992, 2003, 2007, 2008a,c; Schriefers *et al.*, 1990; Starreveld & La Heij, 1996).

5.8.4 Conclusion

To summarise, we obtained additive effects of SOA and stimulus type on picture naming RTs using the PRP procedure. The additivity was obtained regardless of the exact tasks, SOAs, materials, and distractor conditions used. Under structural or strategic response-selection bottleneck and central capacity sharing accounts of dual-task performance, the additivity of stimulus type and SOA effects in all our experiments argues against a pre-selection locus of semantic interference. However, the literature also reports underadditive effects. We concluded that only a strategic scheduling account can accommodate both the additive and underadditive effects. Moreover, the present results suggest that participants have a strong preference for imposing a strategic response-selection bottleneck. However, we have not been able to change this preference. This in turn implies that, as long as we have no clear means of explicitly manipulating potential strategies, conclusions from PRP performance regarding the locus of semantic interference remain tentative.

CHAPTER 6

Event-related potentials and oscillatory brain responses associated with semantic and Stroop-like interference effects in overt naming

Picture-word interference is a widely employed paradigm to investigate lexical access in word production: Speakers name pictures while trying to ignore superimposed distractor words. The distractor can be congruent to the picture (pictured cat, word *cat*), categorically related (pictured cat, word *dog*), or unrelated (pictured cat, word *pen*). Categorically related distractors slow down picture naming relative to unrelated distractors, the so-called semantic interference. Categorically related distractors slow down picture naming relative to congruent distractors, analogous to findings in the colour-word Stroop task. The locus of semantic interference and Stroop-like effects in naming performance has recently become a topic of debate. Whereas some researchers argue for a pre-lexical locus of semantic interference and a lexical locus of Stroop-like effects, others localise both effects at the lexical selection stage. We investigated the time course of semantic and Stroop-like interference effects in overt picture naming by means of event-related potentials (ERP) and time-frequency analyses. Moreover, we employed cluster-based permutation for statistical analyses. Naming latencies showed semantic and Stroop-like interference effects. The ERP waveforms for congruent stimuli started diverging statistically from categorically related stimuli around 250 ms. Deflections for the categorically related condition were more negative-going than for the congruent condition (the Stroop-like effect). The time-frequency analysis revealed a power increase in the beta band (12-30 Hz) for categorically related relative to unrelated stimuli roughly between 250 and 370 ms (the semantic effect). The common time window of these effects suggests that both semantic interference and Stroop-like effects emerged during lexical selection.

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6.1 Introduction

The colour-word Stroop task (Stroop, 1935) has been widely used in the cognitive neurosciences to investigate various aspects of human cognition (e.g., Appelbaum *et al.*, 2009; Balota *et al.*, 2010; Bench *et al.*, 1993; Bub *et al.*, 2006; Lachter *et al.*, 2008; Roelofs *et al.*, 2006; Szucs & Soltész, 2010). In this task, people are required to name the ink colour of written words denoting colours (see MacLeod, 1991, for a review). The written word can be congruent with the name of the ink colour (e.g., *blue* printed in blue ink) or incongruent (e.g., *blue* printed in red ink). The central finding of the Stroop task is that response times (RTs) for the incongruent condition are longer than for the congruent condition, referred to as the Stroop effect. In the past few decades, researchers have also made use of a picture-word analogue of the colour-word Stroop task (e.g., Glaser & Glaser, 1989; La Heij, 1988). In the picture-word interference (PWI) task, speakers have to name pictured objects while trying to ignore written distractor words superimposed onto the pictures. The distractor can be the name of the picture (congruent condition: pictured cat, word *cat*), a categorically related word (related condition: pictured cat, word *dog*), or a categorically unrelated word (unrelated condition: pictured cat, word *pen*). A central finding obtained with PWI is that categorically related distractors slow down picture naming relative to unrelated distractors. Furthermore, categorically related distractors slow down picture naming relative to congruent distractors, a finding which is analogous to that in the colour-word Stroop task. In the remainder of this article, we refer to the PWI contrast between categorically related and congruent conditions as the Stroop-like effect, and the contrast between categorically related and unrelated conditions as semantic interference, following the convention in the literature (e.g., Roelofs, 2003).

Models of Stroop task performance assume processing stages of perceptual and conceptual encoding, response selection, response programming, and response execution (e.g., Dell'Acqua *et al.*, 2007; Roelofs, 2003; Sanders, 1990). Models of picture naming assume perceptual and conceptual encoding, lexical selection, word-form encoding, and articulation as the processing stages (e.g., Levelt *et al.*, 1999; Roelofs, 2003). Response selection in models of Stroop task performance corresponds to lexical selection in models of picture naming, response programming corresponds to word-form encoding, and response execution to articulation (Roelofs, 2003).

Different studies have made use of behavioural measures, neuroimaging, and computational modelling to examine the nature, time course, and neural underpinnings of performance in Stroop-like tasks (e.g., Liotti *et al.*, 2000; Pardo *et al.*, 1990; Roelofs *et al.*, 2006; van Maanen *et al.*, 2009). Although these examinations have yielded many converging findings, researchers have not always found agreement on the interpretation of the results (e.g., Abdel Rahman & Aristei, 2010; Dell'Acqua *et al.*, 2007; Mahon *et al.*, 2007; van Maanen *et al.*, 2009). In the present study, we address one particular issue: the temporal locus of semantic interference and Stroop-like effects in naming tasks. The debate about the locus of the Stroop effect in colour-word Stroop task performance has a long history (see MacLeod, 1991, for a review). Whereas some accounts localise the effect

in perceptual/conceptual encoding (e.g., Hock & Egeth, 1970), other accounts assume a locus close to articulation onset (e.g., Morton, 1969). More recently, computationally implemented accounts of the Stroop phenomenon (e.g., Cohen *et al.*, 1990; Roelofs, 1992, 2003) have localised the Stroop effect in the stage of response selection. According to Roelofs (1992, 2003) and Starreveld and La Heij (1996), among others, the semantic interference effect in PWI also arises in response selection.

The idea that semantic interference and Stroop-like effects emerge during the same processing stage (i.e., lexical selection) was recently called into question by a PWI study conducted by Dell'Acqua et al. (2007), employing the psychological refractory period (PRP) procedure. In their experiment, participants performed a manual tone discrimination task (Task 1) and a PWI task (Task 2). On each trial, a tone stimulus and a picture-word stimulus were presented, each requiring a quick and accurate response. The stimulus onset asynchrony (SOA) between the two task stimuli ranged from 100 ms (short SOA) to 1000 ms (long SOA). Participants were instructed to respond to the tone of Task 1 before responding to the picture-word stimulus of Task 2. RTs were measured to determine the extent to which Task 1 delayed performance of Task 2.

Dell'Acqua et al. (2007) observed that the semantic interference effect was smaller at the short than at the long SOAs. This result was different from earlier findings of Fagot and Pashler (1992) using the colour-word Stroop task with a PRP design, where the effects of Stroop condition (congruent vs. incongruent) and SOA were additive. That is, the magnitude of the Stroop effect was the same at the short and long SOAs. Assuming that the locus of dual-task interference is in response selection (Fagot & Pashler, 1992), this finding confirms other evidence that the Stroop effect arises in selecting a colour-naming response (e.g., Roelofs, 2003). Dell'Acqua et al.'s finding of underadditive semantic and SOA effects was interpreted by the authors as evidence that semantic interference for picture-word stimuli arises earlier than response word selection and, thus, it is not a Stroop-like effect. According to Dell'Acqua et al., the semantic interference effect arises during perceptual/conceptual encoding.

Although Ayora et al. (2011) recently replicated the underadditivity of semantic and SOA effects (in Italian), other researchers obtained additive effects. Schnur and Martin (2012) conducted two experiments with different materials, and slightly different experimental parameters, and failed to replicate Dell'Acqua et al. (2007). One of the experiments used the picture names and word distractors from Dell'Acqua et al. translated into English. In all experiments, equivalent PWI effects were obtained at short and long SOAs following tone identification. Moreover, as shown in Chapter 5 and in Piai and Roelofs (2013), we failed to replicate Dell'Acqua et al. in seven experiments with different materials and parameters, including one experiment that used the picture names and word distractors from Dell'Acqua et al. translated into Dutch. Just as Schnur and Martin, we obtained equivalent PWI effects at short and long SOAs in all experiments. Following the logic of Dell'Acqua et al., the additive semantic and SOA effects suggest that semantic interference arises in lexical selection, unlike what Dell'Acqua et al. assume. Clearly, before the empirical discrepancy between these studies is resolved (see Chapter

2, Piai *et al.*, 2011, for a possible resolution in terms of executive control parameters), it seems premature to assume that the issue of the locus of semantic interference in picture naming has been settled.

Moreover, the conclusion of Dell'Acqua et al. (2007) that the PWI effect is not a Stroop effect was contested by Van Maanen et al. (2009), who argued that the same interference mechanism underlies both effects, although the effects arise at different processing stages. According to the authors, the discrepancy between the findings of Dell'Acqua et al. and Fagot and Pashler (1992) should be attributed to differences in processing speed between pictures (line drawings, which are relatively hard to process) and colours (which are easily identifiable). Because pictures take longer to process than colours, according to Van Maanen and colleagues, Stroop-like and semantic interference effects from distractor words in picture naming occur during perceptual and conceptual encoding (i.e., before response selection), whereas the Stroop effect from distractor words in colour naming occurs during response selection. Van Maanen et al. (2009) presented the results of computer simulations corroborating their claim of a common mechanism but different loci for the effects in PWI and colour-word Stroop studies.

A problem with the simulations of Van Maanen et al. (2009) is that they are based on the assumption of faster colour than picture processing, which is questionable. High temporal-resolution examinations suggest estimates for the time course of colour processing that are not different from estimates for picture shape processing, namely 100-200 ms (e.g., Anllo-Vento *et al.*, 1998; Müller & Keil, 2004; see Dell'Acqua *et al.*, 2010, for a review of some of these studies). This evidence challenges the critical parameters in the simulations of Van Maanen and colleagues.

Another prominent account of the semantic interference effect is the response exclusion hypothesis (e.g., Miozzo & Caramazza, 2003). According to this hypothesis, the semantic interference effect arises after the lexical selection stage, closer to articulation onset. The effect is argued to emerge due to the exclusion of the distractor word from an articulatory buffer (cf. Morton, 1969). The temporal locus of the semantic interference effect stipulated by this account, close to articulation onset, is not easy to investigate with EEG because of artefacts emerging from speech production. Therefore, we do not address this hypothesis in the present study. However, there is accumulating evidence against the response-exclusion account of semantic interference, reported elsewhere (e.g., Abdel Rahman & Aristei, 2010; Mulatti & Coltheart, 2012; Roelofs *et al.*, 2013; Starreveld *et al.*, 2013, and in Chapters 2, 3, and 4).

To summarise, whereas some models assume a common lexical locus of semantic interference and Stroop-like effects in PWI (Roelofs, 1992, 2003; Starreveld & La Heij, 1996), other accounts assume a perceptual/conceptual encoding locus for semantic interference and a lexical selection locus for the Stroop-like effect (Dell'Acqua *et al.*, 2007), or a perceptual/conceptual encoding locus for both semantic interference and Stroop-like effects in the PWI task (van Maanen *et al.*, 2009).

6.1.1 Plan of the present study

The aim of the present study is to adjudicate between the different views on the temporal loci of semantic interference and Stroop-like effects using EEG measures such as event-related potentials (ERPs) and time-frequency representations (TFRs) of power. EEG is an ideal tool to address questions about the timing of processes as it allows for a fine-grained temporal resolution.

Estimates of the timing of processing stages underlying word production were provided by an influential meta-analysis (Indefrey & Levelt, 2004; see also Indefrey, 2011). According to these estimations, based on an average naming latency of 600 ms, the stage of perceptual and conceptual encoding is completed around 200 ms after picture onset, after which lexical selection starts. In the PWI task, mean naming latencies tend to be longer than 600 ms, namely within a range of 700 to 800 ms (e.g., La Heij, 1988; Roelofs, 1992). Taking 750 ms as the mean naming latency (corresponding to what was obtained in the present study), and using a proportional scaling of the estimates to this mean (see Indefrey, 2011), yields 250 ms as the end of the time window of perceptual and conceptual encoding and as the point in time at which the operation of word selection is initiated. This means that, according to the proposal that semantic interference in PWI emerges during perceptual/conceptual encoding (e.g., Dell'Acqua *et al.*, 2007), differences in brain responses between categorically related stimuli (e.g., pictured cat, word *dog*) and unrelated stimuli (e.g., pictured cat, word *pen*) should be seen in a time window that extends at most to 250 ms post-picture onset. Moreover, if Stroop-like effects arise in lexical selection, differences between categorically related stimuli (e.g., pictured cat, word *dog*) and congruent stimuli (e.g., pictured cat, word *cat*) should be detected in a time window starting around 250 ms after picture onset. If, however, semantic interference and Stroop-like effects in PWI both arise in perceptual/conceptual encoding (e.g., van Maanen *et al.*, 2009), both effects should emerge before 250 ms post-picture onset. Finally, if semantic interference and Stroop-like effects both arise during lexical selection (Roelofs, 1992, 2003; Starreveld & La Heij, 1996), these effects should be visible in a time window starting after 250 ms post-picture onset.

Most previous investigations of performance in the colour-word Stroop task using ERPs found a negativity, associated with the incongruent condition relative to the congruent condition, occurring between 300 and 550 ms after stimulus onset with a centro-parietal scalp distribution (e.g., Liotti *et al.*, 2000), suggesting a lexical selection locus of the Stroop effect. Investigations of performance on the PWI task using ERPs did not include the Stroop contrast of congruent versus incongruent stimuli (e.g., Aristei *et al.*, 2011; Hirschfeld *et al.*, 2008), except for a study by Xiao et al. (2010). These authors observed a negative-going potential between 280 and 400 ms for the categorically related condition relative to the congruent condition, with a fronto-central scalp distribution. There are, however, a few reasons why this study does not allow us to draw a conclusion about the temporal locus of semantic interference and Stroop-like effects in PWI. First of all, only three stimuli (i.e., three geometrical shapes) were used as pictures. In contrast,

PWI studies typically include some 20-50 different pictures of various semantic domains, such as animals, tools, etc. (e.g., Aristei *et al.*, 2011; Dell'Acqua *et al.*, 2007; Roelofs, 2003). Moreover, participants responded to the geometrical shapes by pressing keys, so no overt naming was used. Furthermore, for the ERP analysis, there were no a priori defined time windows. The selection of time windows for statistical analyses was based on visual inspection of the data, a procedure prone to bias. Regarding semantic interference in PWI, recent attempts to find this specific effect with ERPs were not successful (e.g., Aristei *et al.*, 2011; Hirschfeld *et al.*, 2008), except for one study (Dell'Acqua *et al.*, 2010), which obtained two semantic interference effects, one with an onset latency of 106 ms and the other starting at 320 ms post-picture onset. However, this study did not include a Stroop-like contrast, precluding a direct comparison of semantic interference and Stroop-like effects.

In the present study, we addressed the issue regarding the timing of the Stroop-like effect and the semantic interference effect in the PWI task by means of electrophysiological measures while participants overtly articulated their responses. The measurement of EEG in overt speech production tasks had long been avoided because of the presumed movement artefacts caused by articulation. However, the use of overt articulation in EEG research is no longer considered problematic (see Eulitz *et al.*, 2000, for a demonstration that ERPs can be analysed using overt naming up to stages of phonetic processing), and an increasing number of studies has made use of this combination successfully (e.g., Aristei *et al.*, 2011; Costa *et al.*, 2009; Hirschfeld *et al.*, 2008; Laganaro & Perret, 2011; Strijkers *et al.*, 2010; Verhoef *et al.*, 2009, 2010). By comparing the brain responses among distractor conditions (i.e., categorically related, unrelated, congruent), it may be assessed when the underlying processes diverge from each other, indicating a time window associated with semantic and Stroop-like effects.

Besides the type of distractor used, we also manipulated the lexical frequency of the picture name. With this kind of manipulation, a word-frequency effect is usually observed: Pictures with high-frequency names are named faster than pictures with low-frequency names (e.g., Oldfield & Wingfield, 1965). Since this effect has been shown to be a lexical effect (Jescheniak & Levelt, 1994; Jescheniak *et al.*, 2003), we used this manipulation as a possible extra marker of lexical processes in our experiment. Regarding the EEG, this lexical-frequency effect should also be observed in time windows related to lexical processes, starting no earlier than 250 ms (cf. Strijkers *et al.*, 2010).

Since we do not have a specific hypothesis for the ERPs regarding the scalp distribution of our effects, an appropriate statistical method must be chosen that allows for testing numerous hypotheses (due to many comparisons of time point by channel), while dealing with the multiple-comparisons problem (cf. Lage-Castellanos *et al.*, 2010). A method that combines the richness of the data with a strict control of the family-wise error rate is cluster-based permutation tests (Maris & Oostenveld, 2007). With this method, no predefined time windows are necessary nor is it required to average the signal within a time-window. This means that we have a method to determine a time window where brain responses differ between conditions in an unbiased way. Note that this

method does not allow us to determine the exact starting point of the earliest divergences between conditions. However, it enables us to determine the time window of the main component of brain responses (cf. Letham & Raij, 2010).

A further aim of the present study was to investigate how the semantic interference and the Stroop-like effects in the PWI task might be reflected in changes in oscillatory brain activity. Whereas ERPs capture mainly evoked activity, i.e., brain responses that are phase-locked to a stimulus, time-frequency analyses reveal changes in oscillatory induced activity, i.e., not necessarily phase-locked, in specific frequency bands over time. Oscillatory activity is modulated by a variety of cognitive factors and is thought to reflect the activity of large ensembles of synchronised neurons (e.g., Buzsáki & Draguhn, 2004). These two approaches to analysing electrophysiological data (i.e., ERP and oscillatory power) are complementary and in some cases, differences in brain signals not evident in terms of ERPs can be revealed in the time-frequency domain (e.g., Mazaheri & Jensen, 2010, Chapter 4).

6.1.2 Summary

The present study investigates the temporal locus of the semantic interference and Stroop-like effects in PWI using EEG with overt articulation (the majority of previous investigations of Stroop task performance used manual responding). Moreover, we conducted analyses of oscillatory power in the context of word production and the PWI task. Finally, we analysed the electrophysiological measures with a method that does not require specific time-windows and channels to be determined a priori, which means we avoid basing our analyses on biased or arbitrary time windows and channels. This method allows us to find a time window at which divergences in the EEG for different conditions become statistically significant, both in the ERPs and in the TFRs of power. If semantic interference occurs in perceptual/conceptual encoding and the Stroop-like effect in response selection, the semantic effect should emerge before 250 ms post-picture onset and the Stroop-like effect after this moment in time. However, if the locus of both the semantic interference and Stroop-like effect in PWI is the perceptual/conceptual encoding stage, both effects should emerge in a time window ending before 250 ms, when perceptual/conceptual encoding is completed. Finally, if the locus of semantic interference and Stroop-like effects is the response-selection stage, both effects should emerge after 250 ms post-picture onset, when lexical selection is initiated.

6.2 Experimental Procedure

Participants. Twenty native speakers of Dutch (6 male) from the participant pool of the Radboud University Nijmegen participated in the experiment. They received a reward of 15 Euros for their participation. All participants were right-handed. They had normal or corrected-to-normal vision and no history of neurological deficits. Participants gave

oral informed consent to their participation after they were completely informed about the nature of the study.

Materials and design. Forty pictures of common objects were selected from the picture gallery of the Max Planck Institute for Psycholinguistics, Nijmegen, together with their Dutch basic-level names. The pictures were white line drawings on a black background, scaled to fit into a frame of 4 cm x 4 cm. Twenty pictures had low-frequency names (mean: 6.49 per million, range: 0.16-14.76) and twenty had high-frequency names (mean: 176.74 per million, range: 42.71-827.45). A list of the materials can be found in Appendix A.7. Each target picture was paired with three different distractor words: 1) the Dutch basic-level name of the picture (congruent condition); 2) a semantically related word (categorically related condition); and 3) a semantically unrelated distractor word (unrelated condition). The unrelated condition was formed by re-pairing the pictures with the categorically related distractors, creating semantically unrelated pairs. The lexical frequency of the distractor words was kept within the range of 14.57-48.11 per million (mean: 28.59) and each distractor was paired once with a picture from the low-frequency condition and once with a picture from the high-frequency condition. There were 120 picture-distractor pairs and the distractor words were not members of the response set, except for the congruent distractors, which were the names of the pictures. The distractor words were presented in font Arial size 36, colour white. The picture-word pairs were presented three times in a blocked manner, i.e., a given picture could only appear for the second time after all pictures had already been presented once, and so on. The two independent variables (distractor type and lexical frequency of the picture name) were manipulated within-participants. The lexical frequency of the picture name was manipulated between-items and distractor type was manipulated within-items. One unique stimulus list was used per participant using Mix for randomisation (van Casteren & Davis, 2006). The following constraints were applied: a) there were at least 15 pictures intervening between one presentation of a certain picture and its next presentation; and b) a given distractor type condition and a given lexical-frequency condition could not be repeated more than three consecutive times. The 40 pictures were also used for a naming practice session, in which they appeared twice. One unique randomisation was used per participant for the naming practice.

The experimental pictures were evaluated in a pre-test with respect to differences in ease of recognition, using a picture recognition task (e.g., Özdemir *et al.*, 2007). Ten native speakers of Dutch (3 male), none of which took part in the EEG experiment, performed the picture recognition task. Forty additional pictures, which were used as filler items, were selected from the same picture gallery as for the experimental materials, also subdivided into high-frequency (20 pictures) and low-frequency names (20 pictures), with the same lexical characteristics as the experimental items. One unique randomisation was used per participant with the same lexical-frequency type appearing at most in three consecutive trials. A written word was presented in the centre of the screen for 500 ms. A black screen followed for 500 ms, followed by a picture presented in the centre of the

screen for 1 s. Participants indicated with a button press whether the written word and the object referred to the same entity, by pressing the "yes" button, or not, by pressing the "no" button. Whether the "yes" button would be the right or the left button was counterbalanced across participants. In the case of the experimental items, the word and the picture always referred to the same entity; the filler pictures were always preceded by a different word. We analysed only the RTs to the experimental items with correct button presses. Errors were not analysed, due to their very low occurrence. Mean RTs were 455 ms for the high-frequency condition and 467 for the low-frequency condition. These conditions did not differ in ease of recognition, Fs < 1. So we can conclude that, if we find differences in the naming RTs or in the EEG between high-frequency and low-frequency picture names, then these effects are related to lexical effects, since the pictures are recognised equally fast in the two lexical-frequency conditions.

Procedure and apparatus. Participants were seated comfortably in an electrically and acoustically shielded booth in front of a computer monitor, approximately 50 cm away from it. The presentation of stimuli and the recording of responses were controlled by Presentation Software (Neurobehavioral Systems). Vocal responses were measured with a voice key. Before the experiment, participants were given a booklet to get familiarised with the pictures used in the experiment and their names. They were instructed to name the pictures and to ignore the printed words. Next, a naming practice was administered, during which the experimental pictures appeared unobstructed on the screen for 1 s, followed by a black screen for 500 ms. Participants named the pictures and were corrected after the naming practice if they had used the wrong name. A PWI practice session of eight trials followed, in which 3 non-experimental pictures were presented with semantically unrelated distractors following the same trial structure as the experimental session. The experiment proper followed the practice sessions.

An experimental trial began with the picture and the distractor word being presented on the centre of the screen for 250 ms. Then a black screen was presented for 1250 ms plus a jitter. Jitter durations varied randomly between 350, 500 and 750 ms. The use of this trial structure was motivated by findings that anticipated stimuli evoke a slow wave in the EEG (Walter *et al.*, 1964). The absence of a fixation point at the beginning of a trial and the varying jitter durations prevent participants from anticipating the beginning of each trial, thereby minimizing the presence of expectancy slow-waves in the data. The registration of the vocal responses started as soon as the stimuli were displayed on the screen. There were in total six short breaks, during which participants were allowed to drink water and rest, and they indicated when they were ready to proceed. The whole session, including participant preparation, lasted approximately 1 h and 15 min.

EEG recording and pre-processing. EEG was recorded from 60 scalp electrodes mounted equi-distantly in an elastic cap, positioned according to the international 10-20 system, using the Acticap system, amplified with BrainAmps DC amplifiers (500 Hz sampling, 0.016-100 Hz band-pass). Each electrode was referenced on-line to the left mastoid and re-referenced off-line to averaged mastoids. The horizontal electrooculogram

was reconstructed from the electrodes placed on the left and right temples. The vertical electrooculogram was reconstructed from the electrodes positioned below and above the left eye. Electrode impedance was kept below 5 kΩ. Four channels (T7, T8, F7, F8) were excluded from subsequent analyses due to large amount of noise in the data of four participants. All EEG analyses were performed using the FieldTrip open source Matlab toolbox (Oostenveld *et al.*, 2011).

RT analysis. At each trial, the experimenter evaluated the participants' vocal responses. Trials in which the voice key was triggered by a sound which was not the participant's response and naming RTs shorter than 200 ms were discarded. Responses which contained a disfluency, a wrong pronunciation of the word, or a wrong response word were coded as errors. These trials were included in the error analysis and were subsequently excluded from the analyses of the naming RTs. We submitted RTs to by-participant (F_1) and by-item (F_2) analyses of variance with the independent variables distractor type (congruent, categorically related, and unrelated) and lexical frequency (high and low). Moreover, 95% confidence intervals (CI) are reported for the semantic interference, lexical frequency and Stroop-like effects. Errors were submitted to logistic regression analyses.

ERP analysis. All trials excluded from the RT analysis were also excluded from the ERP analysis. Additionally, trials with RT lower than 600 ms were also excluded to avoid contamination of the EEG data with artefacts from articulation onset. Single waveforms were filtered with a bandpass filter of 0.1 to 20 Hz. Next, the continuous EEG was segmented into stimulus time-locked epochs, starting at 200 ms before stimulus onset and lasting until 500 ms after stimulus onset. The segments were then baseline-corrected using the average EEG activity from the 200 ms prior to stimulus onset. Trials which contained eye movements, electrode drifting and muscular artefacts within the epoch were rejected. In total, 12.3% of the data was discarded, either already in the RT analysis or after artefact rejection. At least 60 trials remained in each level of each independent variable for each participant. Averaged ERPs were computed for each participant across trials for each level of the distractor type condition (collapsed over lexical frequency) and for each level of the lexical-frequency condition (only the categorically related and unrelated conditions were included). The reason for collapsing over conditions was the following. The congruent condition is of a different nature than the categorically related and unrelated conditions in the sense that in the former, the name of the picture is also the distractor word, whereas in the latter, the distractor words are never the name of the picture, i.e., both conditions are "incongruent" in this respect. If we computed the lexical-frequency brain responses pooling over all conditions, we could affect the nature of the signal. Furthermore, the RTs for categorically related and unrelated conditions tend not to differ more than 50 ms on average, whereas they tend to differ much more from the congruent condition (e.g., Roelofs, 2007). By averaging over conditions with such different RTs, effects could be washed-out. Therefore, we only collapsed over conditions with more similar RTs for the lexical-frequency conditions. Finally, both levels of the lexical-frequency manipulation occurred in all three distractor-type conditions, so in principle, collapsing over levels of

one or the other condition is not problematic.

Time-frequency analysis of oscillatory power. All trials excluded from the RT analysis and trials with RT lower than 600 ms were excluded from the time-frequency analysis. Additionally, trials which contained eye movements, electrode drifting and muscular artefacts within the epoch were rejected (13% of the data). Two participants were excluded from this analysis due to the high occurrence of noise in the higher frequency bands. Note that this difference in rejection rate is due to the low-pass filter applied for the ERPs (20 Hz), which was not used for the time-frequency procedure (and the two excluded participants had too much noise in the frequencies above 20 Hz). In order to remove power line noise, the data was filtered by removing the two coefficients centred at 50 and 100 Hz from its Fourier transform, followed by the inverse Fourier transform. The continuous EEG was then segmented in epochs starting at 200 ms prior to picture onset until 500 ms. To analyse changes in oscillatory power, time-frequency representations (TFRs) of power were computed using a sliding time-window approach. To optimise the trade-off between frequency and time resolution, two different approaches were used. For the low-frequency range (5-30 Hz), power was calculated per trial using 200 ms time-windows. The data in each time-window was multiplied with a Hanning-taper followed by a Fourier transform to get a power estimate. Due to the length of the time-windows, power can only be estimated between 100 ms pre-stimulus and 400 ms post-stimulus. For the high-frequency range (30-100 Hz), we used a multi-taper approach (Percival & Walden, 1993) with 200 ms sliding time-windows. The data of each time-window was multiplied with an orthogonal set of tapers taken from the Discrete Prolate Spheroidal Sequences. A frequency smoothing of $\Delta f = 16$ Hz was used, resulting in 3 tapers being applied to the data. Power values were then obtained by taking the Fourier transforms of the tapered data-segment and averaging over the tapers per trial (see Nieuwenhuis *et al.*, 2008, for similar settings). The TFRs of power were then averaged over trials per participant for each distractor type condition and differences in power between conditions were calculated as a relative difference (i.e., the difference in power between two conditions divided by the sum of the power of those two conditions). This relative power difference was subsequently analysed with cluster-based permutation tests.

Statistical analysis of ERPs and TFRs of power. Significance of the differences between conditions was tested using a non-parametric cluster-based permutation procedure (Maris & Oostenveld, 2007). This statistical approach allows one to take full advantage of the multiple time and channel information in the data, while dealing with the multiple-comparisons problem. We briefly describe the procedure here, but we refer to Maris and Oostenveld (2007) for a detailed description of the approach (see also Groppe *et al.*, 2011).

First, for every channel-time point of the ERPs or channel-time-frequency point of the TFRs of power, a dependent-samples t-value is calculated. Note that these t-values are not used for statistical inference nor are they used to calculate the significance probability of the cluster. For the analyses of the semantic interference and Stroop-like effects, all available time points were taken, i.e., from 200 ms pre-stimulus to 500 ms

post-stimulus. For the lexical-frequency analysis, the selection of time points included in the analyses (from 180 ms to 500 ms post-stimulus) was based on the effect found by Strijkers et al. (2010). All pairs whose t-values are larger than a pre-determined threshold, in our case ± 1.75, are selected and clustered on the basis of temporal and spatial adjacency (and frequency adjacency for the TFRs). For the spatial adjacency, channels were set to have, on average, two neighbours. For the temporal adjacency, the criterion was one time point and for the frequency adjacency, 1 frequency unit. For each cluster, a cluster-level statistic is calculated by taking the sum of the t-values within that cluster. The significance of the clusters is then calculated with a Monte Carlo method. For that, a permutation distribution is created in the following way: A random partition is created by randomly pairing participant averages of one condition to the other condition, followed by calculating dependent-samples t-values. These are then thresholded and subsequently clustered (same as above). The maximum of the cluster-level summed t-values is then taken and selected to enter the permutation distribution. This procedure is repeated 1000 times. All cluster-level statistics from the observed data are then compared to the resulting permutation distribution. The proportion of random partitions that yielded a larger test statistic than that of the observed cluster is then taken as the Monte Carlo estimate of the p-value. Using a critical alpha-level of .05, we conclude that two experimental conditions are significantly different if this Monte Carlo p-value is smaller than the alpha-level. The family-wise error rate is kept at .05 because all clusters are compared to the permutation distribution constructed using the maximum cluster-level statistic (see Maris & Oostenveld, 2007).

6.3 Results

6.3.1 Behavioural data

The error percentages for the different distractor types were 1.2% for the congruent condition, 3.4% for the categorically related condition, and 2.6% for the unrelated condition; and 2.5% for high-frequency and 2.3% for low-frequency picture names. The logistic regression model indicated that, relative to the congruent condition, categorically related distractors caused the log-odds of an incorrect response to increase by a factor of 2.9, β *coefficient* = -1.05, *S.E.* = .31, *Wald Z* = -3.3, $p < .001$; and unrelated distractors increased the log-odds of an incorrect response by a factor of 2.7, β *coefficient* = -1, *S.E.* = .32, *Wald Z* = -3.1, $p = .002$. Categorically related distractors did not differ from unrelated distractors, $p = .800$. Lexical frequency was not a significant predictor in the regression model, $p = 1.0$.

Figure 6.1(A) shows the box-and-whisker diagram for the RTs, with the median and the distribution for each condition (the ends of the whiskers represent the lowest and highest data point within 1.5 interquartile range). A main effect of distractor type was found, $F_1(2,38) = 150.86$, $p < .001$, $F_2(2,76) = 187.91$, $p < .001$. Contrasts revealed a semantic interference effect (26 ms), $F_1(1,19) = 34.04$, $p < .001$, $F_2(1,39) = 10.80$, $p =$

.002, 95% *CI* (17, 36), and a Stroop-like effect (125 ms), $F_1(1,19) = 200.66$, $p < .001$, $F_2(1,39) = 364.57$, $p < .001$, 95% *CI* (107, 145). The mean RTs for the high-frequency and low-frequency conditions were 749 ms and 757 ms respectively. The lexical frequency effect was only found in the analysis by participants, $F_1(1,19) = 5.65$, $p = .028$, $F_2(1,38) < 1$, 95% *CI* (-16, 0.2). No interaction was found between distractor type and lexical frequency, Fs < 1.

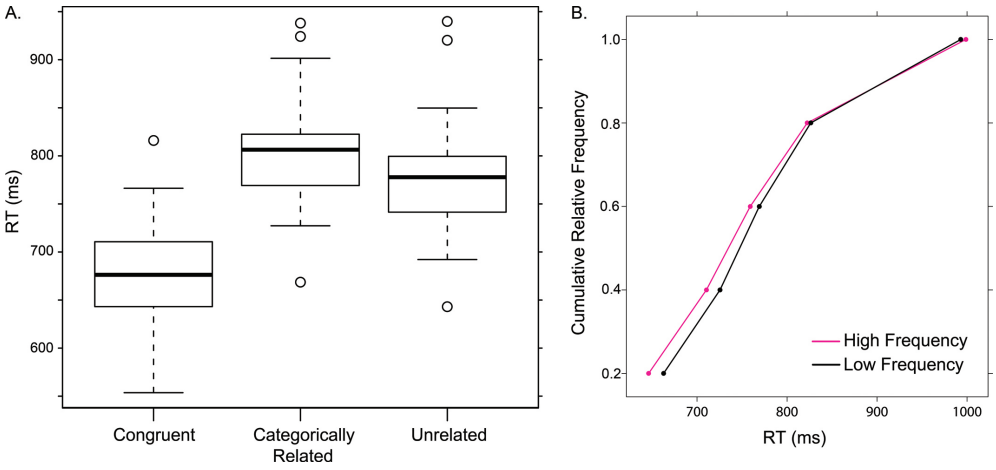

Figure 6.1: Behavioural data. (A) Box-and-whisker diagram of the naming RTs as a function of distractor type. (B) Vincentised cumulative distribution curves for the high-frequency (pink line) and low-frequency (black line) conditions. RT = response time.

Since the lexical-frequency effect was not robust in the mean RTs, we also performed Vincentile analyses to examine the shape of the RT distribution. We divided the rank-ordered RTs for each participant into 20% quantiles and computed quantile means for each lexical-frequency condition. The quantiles were then averaged across participants. This technique allows the detection of opposite underlying effects possibly giving rise to null effects in the mean RTs (e.g., Heathcote *et al.*, 1991).

Figure 6.1(B) shows the Vincentised cumulative distribution curves for the lexical-frequency effect. The high-frequency condition clearly yields shorter RTs than the low-frequency condition, except for the 20% slowest responses. Thus the RT distribution analysis shows that the lexical-frequency effect is only absent towards the tail of the distribution.

6.3.2 ERP data

Grand-average ERPs for the three distractor types, collapsed over high- and low-frequency conditions, are shown in Figure 6.2(A) for nine representative channels (coloured red in Figure 6.2(B); there is a one-to-one correspondence between the orientation of the

channels in Figures 6.2(A) and (B)). For the Stroop-like effect, starting around 250 ms, amplitudes for the congruent condition become larger than for the categorically related condition, and this difference tends to increase with time. For the semantic interference effect, there are no visible differences in the waveforms between the categorically related and unrelated conditions.

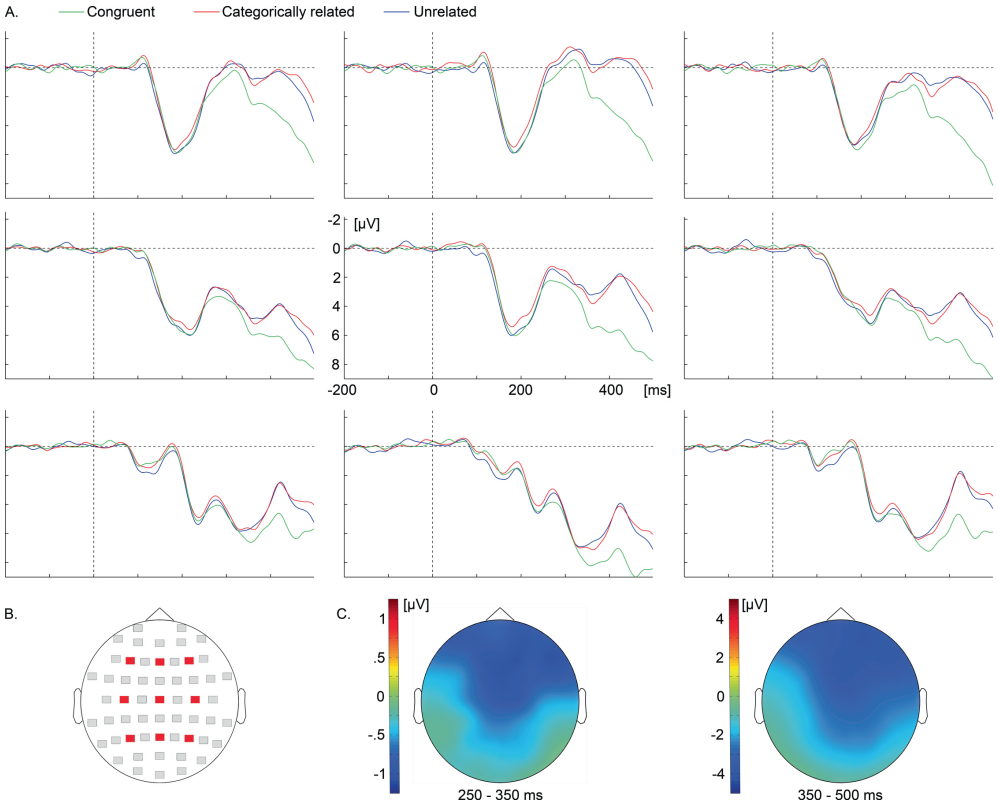

Figure 6.2: ERPs to stimulus-type conditions. (A) ERPs to the three distractor types: congruent (green line), categorically related (red line), and unrelated (blue line). (B) EEG-cap configuration. Each rectangle corresponds to a channel. The red channels are the channels for which the ERPs are shown. There is a one-to-one correspondence between the orientation of the channels in red in (B) and the ERPs in (A). (C) Scalp distribution of the Stroop-like effect, averaged over the time window 250-350 ms (left) and 350-500 ms (right).

For the Stroop-like effect, a negative statistically significant cluster was detected, starting at 254 ms and lasting until the end of the segment (i.e., 500 ms), $p < .001$. The cluster was first detected in fronto-central electrodes (as shown in the left scalp topography in Figure 6.2(C)), extending later to centro-parietal electrodes (as shown in the right scalp topography in Figure 6.2(C)). For the semantic interference effect, no significant clusters were detected.

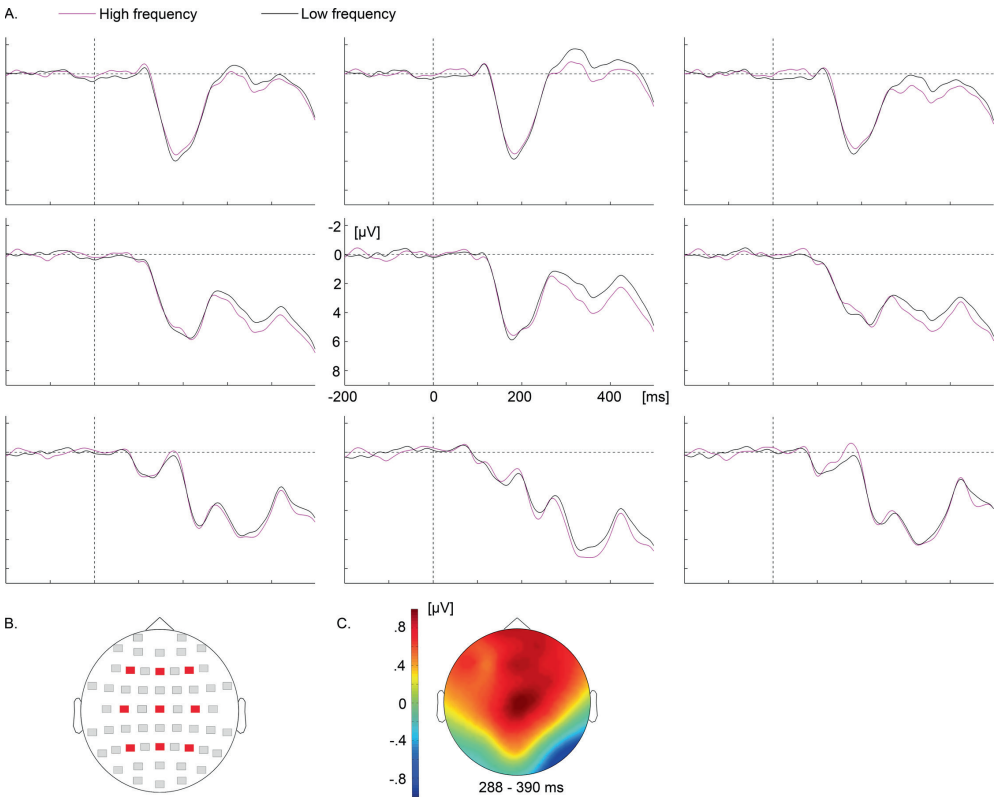

Figure 6.3: ERPs to lexical-frequency conditions. (A) ERPs to the high-frequency (pink line) and low-frequency (black line) conditions. (B) EEG-cap configuration. Each rectangle corresponds to a channel. The red channels are the channels for which the ERPs are shown. There is a one-to-one correspondence between the orientation of the channels in red in (B) and the ERPs in (A). (C) Scalp distribution of the lexical-frequency effect (high-frequency minus low-frequency condition), averaged over the time window 288-390 ms.

Grand-average ERPs for the two lexical-frequency conditions, collapsed over the categorically related and unrelated conditions, are shown in Figure 6.3(A) for nine representative channels (coloured red in Figure 6.3(B); there is a one-to-one correspondence between the orientation of the channels in Figures 6.3(A) and (B)). Starting around 260 ms, amplitudes for the high-frequency condition become more positive-going relative to the low-frequency condition. A positive statistically significant cluster was detected between 288 ms and 390 ms, $p = .042$. The cluster was detected in fronto-central electrodes (as shown in the scalp topography in Figure 6.3(C)).

6.3.3 Time-frequency data

Power spectra revealed increased relative power in the beta band for the categorically related condition compared to the unrelated condition approximately between 210 and 380 ms (Figure 6.4(A)). Statistical testing identified a significant cluster with a frequency range of approximately 15-27 Hz and a time range of approximately 230-370 ms, present in 15 channels (coloured red in Figure 6.4(B)), $p = .019$. This effect is most prominent in central channels, slightly right-lateralised, as shown in the scalp topography in Figure 6.4(C). No significant clusters were detected either for the Stroop-like effect or for the lexical-frequency effect. Finally, no significant clusters were detected in the high-frequency range (i.e., 30-100 Hz).

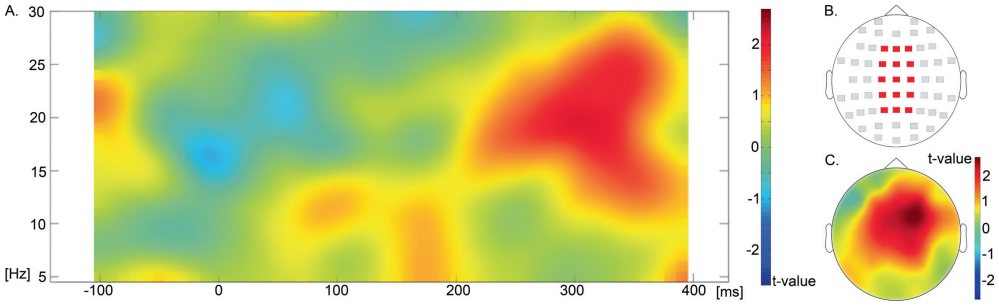

Figure 6.4: Time-frequency data. (A) Time resolved power spectrum of the semantic interference effect, averaged over the channels in red in panel B. (B) EEG-cap configuration. Each rectangle corresponds to a channel. The red channels are the channels for which the averaged power spectrum is plotted. (C) Scalp distribution of the semantic interference effect, averaged over the time window 230-370ms.

6.4 Discussion

The present EEG experiment examined the timing of semantic interference and Stroop-like effects in the PWI task. We investigated whether the timing of the ERP effects suggests a lexical selection locus of both effects (Roelofs, 2003), a perceptual/conceptual locus for the semantic interference effect and a lexical selection locus for the Stroop-like effect (Dell'Acqua *et al.*, 2007), or a perceptual/conceptual encoding locus for both semantic interference and Stroop-like effects in PWI (van Maanen *et al.*, 2009).

Our RT data revealed a Stroop-like effect (i.e., pictures paired with categorically related distractors were named more slowly and less accurately relative to congruent pairs) and a semantic interference effect (i.e., categorically related pairs were named more slowly than unrelated pairs). The effect of lexical frequency in the RTs was less robust, and absent in the relatively slow responses. Regarding the ERPs, a statistically significant negativity was detected for categorically related stimuli relative to congruent stimuli (the

Stroop-like effect), in a time window starting around 250 ms and lasting until the last analysed segment at 500 ms. The effect started with a fronto-central scalp distribution, spreading later slightly to centro-parietal channels. The scalp distribution of the effect, however, was very similar between 250-350 ms and 350-500 ms. A lexical-frequency effect was detected roughly between 290 ms and 390 ms mainly in fronto-central channels, with the high-frequency condition eliciting a more positive-going wave relative to the low-frequency condition. No statistically significant clusters were detected corresponding to the semantic interference effect in the ERPs, in line with other studies (e.g., Aristei *et al.*, 2011; Hirschfeld *et al.*, 2008; but see Dell'Acqua *et al.*, 2010). However, in the time-frequency domain, a statistically significant relative power increase in the beta-band was observed for categorically related stimuli compared to unrelated stimuli (the semantic interference effect) between 230 and 370 ms. Due to the intrinsic temporal smearing in the time-frequency estimations, the latency of this beta effect cannot be taken strictly as revealing the precise timing of the underlying neural processes, so the time window of this effect should be seen as an approximation of the time window of the semantic interference effect.

The lexical-frequency effect in the current experiment was small and not robust in the mean RTs. Although we are not certain why, this weakness could be attributable to the use of the PWI paradigm (previous reports of the lexical-frequency effect did not use the PWI paradigm, e.g., Jescheniak & Levelt, 1994; Jescheniak *et al.*, 2003; Oldfield & Wingfield, 1965). In the ERPs, although small, this effect was significant between roughly 290 ms and 390 ms. Our time course diverges slightly from the interval of 150-200 ms for the frequency effect obtained by Strijkers et al. (2010), but they used a standard picture naming task, with no distractor words. Standard picture naming yields shorter RTs than picture naming in PWI, as was the case in our experiment (PWI, mean naming RT around 750 ms) compared to Strijkers et al. (standard naming, mean naming RT around 700 ms). Thus the time shift of our effect compared to the effect of Strijkers et al. may be due to the presence of the distractor word.

Our ERP results for the Stroop-like effect are similar to Xiao et al.'s (2010) study, in which a fronto-central negativity was observed for the categorically related relative to the congruent condition in two time windows, 280-400 ms (the time window paralleling our results) and 530-600 ms. Similarly, in the colour-word Stroop task, a fronto-central negativity between 350 and 500 ms was found for the incongruent relative to the congruent condition (Liotti *et al.*, 2000).

Lexical selection in word production is estimated to start between 200 and 250 ms after stimulus onset and to last until around 350 ms (e.g., Indefrey & Levelt, 2004; Sahin *et al.*, 2009). The time window for which we found a significant cluster for the lexical-frequency effect largely agrees with these estimates. Moreover, significant clusters were found between 254 and 500 ms for the Stroop-like effect in the ERPs and 230 and 370 ms for the semantic effect in the TFRs. These time windows overlap with the estimated time window of the lexical selection stage. Finally, taking the lexical-frequency effect as a marker of lexical access in the present data, the time windows of the interference effects

also generally overlap with the time window of the lexical-frequency effect. Thus, the results from the ERP and time-frequency analyses do not agree with accounts that localise the semantic and Stroop-like interference effects in a stage prior to lexical selection (i.e., van Maanen *et al.*, 2009) or the semantic effect prior to lexical selection (i.e., Dell'Acqua *et al.*, 2007). Therefore, the present data are mostly consistent with accounts of semantic and Stroop-like effects that place both effects at the stage of lexical selection (Roelofs, 1992, 2003; Starreveld & La Heij, 1996).

One could argue that the overlap in time of the present effects is in fact, contrary to what we claim, minimal (only between 288 and 370 ms). We would like to argue, firstly, that especially the onset of the overlapping statistical effects is important, rather than their offset. This is because the onset of the stage of lexical selection is, in fact, easier to estimate than its duration. In the case of lexical selection, only conceptual processing occurred before it. Thus the onset of the lexical selection stage can be estimated on the basis of the estimated end of the previous process. Going further down the chain of processes, an accumulated margin of error makes estimates less precise (see Indefrey, 2011; Indefrey & Levelt, 2004). Secondly, the timing of the effects used in our argument of overlapping timing is based on the exact timing of the statistically significant clusters detected in our data. Although we did not test explicitly for the onset of ERP latency differences (see Kiesel *et al.*, 2008), our time windows for statistical testing were not selected a priori. The statistical method we used, cluster-based permutation, tends to be a conservative test when compared to testing pre-defined time windows (cf. Groppe *et al.*, 2011). From this perspective, the fact that the clusters of the three effects were detected starting between 230 and 288 ms points to an overlap that is not minimal. Thirdly, the lack of an overlap of offsets across the three effects (500 ms for the Stroop-like effect, and 370 and 390 ms for the semantic interference and lexical frequency effects, respectively) may be only apparent. The overlap between the lexical frequency and semantic interference effects is clear. For the Stroop-like effect, the fact that the cluster extends until 500 ms could easily be explained by the overlap of ERP components following the component elicited around 250 ms (e.g., Woodman, 2010). So we do not consider the offset of 500 ms as indicative for the duration of the lexical selection stage in the present study. Given these considerations, the temporal overlap of the three effects becomes more evident. Finally, the onset of the effects is similar to the onset of the effects related to lexical selection reviewed by Indefrey (2011), which provided an updated onset estimate of 200 ms for the lexical selection stage.

An objection could be made to the proportional scaling we applied to our time estimates. For example, some researchers argue that the onset of lexical access is fixed (Costa *et al.*, 2009). However, there is also a reason to assume that a certain amount of rescaling should be used (see also Indefrey, 2011). For example, when presenting pictures alone, perceptual and conceptual encoding will be recruited for processing the picture. But if a distractor word is presented on top of the picture, there is clearly more perceptual information being provided, which potentially affects the perceptual encoding

stage. Evidence for this influence can be seen, for example, in the fact that picture naming RTs are always shorter for pictures alone relative to pictures with an unrelated word distractor, a pronounceable pseudoword, or even consonant strings or a series of Xs (e.g., Lupker, 1982). So some sort of proportional scaling of the early stages of perception for picture-word stimuli is not entirely implausible. But crucial for the argument being pursued in the present study, even if one does not rescale the time estimates, then 200 ms should be our reference point. All effects observed in the present study occur later than 200 ms, thus decreasing the plausibility of models which localise the Stroop-like and semantic interference effects in stages preceding lexical selection.

Finally, an apparent discrepancy is found between the present lack of an ERP effect for the semantic interference effect and the presence of such effect in Dell'Acqua et al. (2010). Dell'Acqua et al. obtained two effects related to semantic interference, one starting at 106 ms and the other at around 320 ms. Note, however, that other studies also did not obtain semantic interference effects from distractor words in the ERPs (Aristei *et al.*, 2011; Hirschfeld *et al.*, 2008). Moreover, Dell'Acqua et al.'s interpretation of the effect at 320 ms is that it reflects processing at the lexical selection stage, which is in line with the current proposal. Different from the present ERP study, Dell'Acqua et al. (2010) did not pre-expose the materials to participants prior to collecting ERP and behavioural data. This raises the possibility that the early 106-ms semantic effect observed by Dell'Acqua et al. arose during perceptual/conceptual encoding because of the first-time processing of the pictures and words. In contrast, the later semantic effect (at 320 ms in Dell'Acqua et al. and between 250 and 370 ms in our study) is obtained regardless of pre-exposure to the materials, which suggests that the semantic effect arising in lexical selection is independent of a familiarisation with the pictures and words.

6.4.1 Difference in the electrophysiology of semantic and Stroop-like interference

The difference between distractor-word effects in the ERPs (i.e., the Stroop-like effect) and in the TFRs (i.e., the semantic interference effect) raises an important question. If Stroop-like and semantic interference both arise during lexical selection, one could argue that both effects should surface as the same electrophysiological effect, for example, both effects as relative beta-power increase. The difference in electrophysiological effects may be interpreted as evidence for distinct functional loci of Stroop-like and semantic interference effects. For example, one may argue that the semantic effect in the TFRs reflects conceptual level processing, whereas the Stroop-like effect in the ERPs reflects lexical level processing, in line with the functional account of Dell'Acqua et al. (2007). However, a problem with this interpretation is that the assumption of different functional loci for the effects (i.e., conceptual and lexical stages) is not compatible with the timing of the effects in the TFRs and ERPs, which suggests that the electrophysiological effects occur in roughly the same time window. Moreover, in this time window, also the lexical frequency effect occurs, suggesting a lexical selection locus of all three effects (i.e., Stroop-

like, semantic, lexical frequency). Therefore, we make a distinction between a functional locus interpretation and a temporal locus interpretation of the present effects, which we explain below. We assume that the different electrophysiological effects (ERPs vs. TFRs) reflect a functional difference, i.e., the difference in processing and attentional control demands of the words in the different conditions (cf. Roelofs, 2003). The experimental contrast used for assessing the semantic interference effect involves two conditions for which the distractor word is incongruent with the picture name (i.e., categorically related and unrelated distractor words), whereas one of the conditions used in the Stroop-like contrast is a congruent condition (i.e., the name of the picture itself). The (categorically related and unrelated) incongruent conditions may recruit different or additional brain areas, or the same areas to different degrees, as compared to the congruent condition, where even reading the distractor word would yield a correct response. Evidence suggests that incongruent distractors trigger attentional control processes that deal with the interference, whereas such a process is not (or to a lesser extent) needed for congruent distractors (e.g., Roelofs *et al.*, 2006). The different processing and attentional demands of the different distractor types may affect the nature of the signal that is measured at the scalp, as observed in our experiment. However, given the time course evidence, it seems plausible to assume that these two effects have a common temporal locus, i.e., they emerge during the same planning stage (lexical selection) in the course of word production processes. To conclude, whereas the timing of the Stroop-like, semantic interference, and lexical frequency effects suggests a common lexical locus (the temporal interpretation), the different electrophysiological manifestation of the effects (i.e., ERPs vs. TFRs) suggests differences in processing and attentional demands among the distractor conditions (the functional interpretation).

6.4.2 Beta oscillations in PWI and word production

Beta-band activity has been reported especially in the sensorimotor domain in relation to motor preparation and execution, and recently also in relation to expectancy (e.g., Engel & Fries, 2010; Neuper *et al.*, 2006). In the language domain, investigations of oscillatory activity so far have been confined to language comprehension (e.g., Bastiaansen *et al.*, 2008; Röhm *et al.*, 2001; Wang *et al.*, 2012) whereas there are no reports in the literature related to language production paradigms (but see Saarinen *et al.*, 2006; Salmelin & Sams, 2002, for oscillatory and motor-cortex activity related to mouth movements).

Since beta desynchronisation has been consistently found in relation to motor preparation (see e.g., Neuper *et al.*, 2006; Saarinen *et al.*, 2006), one could argue that our beta power increase for the semantic effect reflects differences in motor preparation between the categorically related and unrelated conditions. For example, in earlier studies, motor cortex activity was found while preparing and executing mouth movements, quantified by a pattern of suppression followed by rebound of the 20-Hz rhythm (Saarinen *et al.*, 2006; Salmelin & Sams, 2002). Since participants are slightly faster in the unrelated than in the categorically related condition, motor preparation (and thus beta desynchro-

nisation) in the former should start earlier than in the latter. This would explain why there is more power for the related relative to the unrelated condition.

There are reasons to believe, however, that differences in motor preparation between the categorically related and unrelated conditions cannot alone account for the present beta effect. Firstly, evidence suggests that around 250 ms, participants are still in the process of selecting the word to be produced (cf. Indefrey & Levelt, 2004; Sahin *et al.*, 2009). It is unlikely that participants could start preparing the articulatory programme of a given word while not having selected the word. Models of word production agree on the assumption that motor preparation (referred to as phonetic encoding in Indefrey & Levelt, 2004) is the last step before articulation, which in our study happened on average around 750 ms after picture onset. In Sahin et al.'s (2009) study, which used intracranial EEG, phonological encoding did not start before 450 ms in a word generation task, which usually yields RTs around 600 ms (e.g., Roelofs, 2006). Our RTs were certainly longer, which should place the beginning of phonological encoding even further away from 450 ms. Besides, motor representations are only engaged in the last substages of phonological encoding (e.g., Indefrey & Levelt, 2004; Levelt *et al.*, 1999). Moreover, as noted by Sahin et al. (2009), motor neuron commands are issued between 50 and 100 ms before speech onset. For the trials included in the EEG analyses in the present study, participants' individual mean RTs for the distractor-type conditions are above 732 ms. Working backwards from the RTs, our participants must have engaged in phonological encoding no earlier than 450-500 ms after picture onset. Furthermore, Saarinen et al. (2006) observed that the onset of the 20-Hz suppression preceded the mouth electromyogram by no more than 150 ms on average. These time points cannot, of course, be taken as absolute when considering the time-frequency domain since time-frequency estimates are smeared both in time and in frequency.

Regarding the scalp topography of the beta power effect, using magnetoencephalography (MEG), Saarinen and colleagues found that the onset and offset of the 20-Hz activity in the left hemisphere preceded that in the right hemisphere. The scalp topography of our beta effect, on the contrary, is quite right lateralised, although a comparison between MEG and EEG scalp topographies is not straightforward. Finally, if the beta effect was simply reflecting motor preparation, a similar beta power modulation should have been found for the lexical-frequency effect and for the Stroop-like effect, or an even stronger modulation in the latter case, since differences in RTs are larger between the categorically related and congruent conditions than between the related and unrelated conditions.

Note that we do not exclude the possibility that there may be some kind of general motor preparation already at earlier stages of word production, for example, during lexical selection. Participants are engaged in a task for which they know a motor response is required at every trial so general aspects of preparation may be at play quite early. However, we do not think that this general motor preparation should be condition specific already during the stage of lexical selection. Given the arguments outlined above, altogether, it seems that the beta power increase in the present study cannot be simply

accounted for in terms of motor preparation.

Alternatively, beta activity may relate to the engagement and disengagement of specific brain regions (e.g., Engel & Fries, 2010; Haegens *et al.*, 2011; Jensen & Mazaheri, 2010; van Wijk *et al.*, 2009; Wang *et al.*, 2012). According to this view, neuronal synchronisation in a specific band (e.g., gamma band) may reflect the engagement of certain brain areas in processing the current task, whereas other frequency bands (e.g., alpha band) are argued to play a role in inhibiting task-irrelevant areas (see e.g., Jensen & Mazaheri, 2010). The beta oscillations captured by our EEG recordings might be reflecting a similar inhibitory mechanism. In the categorically related condition, the disengagement of processes related to word reading must be stronger than in the unrelated condition. Note that this hypothesis is still speculative. More replications of this effect are needed before conclusions can be drawn regarding what aspects of the lexical-selection process and motor preparation are being reflected in the oscillatory activity. For example, source localisation of the beta modulation could provide very helpful information to help interpret this effect.

6.5 Summary and Conclusions

In summary, we investigated participants' overt naming performance in the PWI task while recording their EEG. Naming RTs showed the expected semantic interference and Stroop-like effects. The ERP waveforms for congruent stimuli started diverging statistically from categorically related stimuli around 250 ms with more negative-going deflections than the congruent condition: the Stroop-like effect. The time-frequency analysis revealed oscillatory power increase approximately between 15 and 27 Hz for categorically related stimuli relative to unrelated stimuli roughly between 230 and 370 ms: the semantic interference effect. Finally, effects of lexical frequency emerged between 288 and 390 ms. The common time window of these effects suggests that both semantic interference and Stroop-like effects emerged during lexical selection.

CHAPTER 7

Attention for speaking: domain-general control from the anterior cingulate cortex in spoken word production

Accumulating evidence suggests that some degree of attentional control is required to regulate and monitor processes underlying speaking. In the past few years, much progress has been made in delineating the neural substrates of the core language processes involved in speaking. Despite this progress, the neural substrates associated with regulatory and monitoring processes have remained relatively underspecified. Here, we report the results of an fMRI study examining the neural substrates related to performance in three attention-demanding tasks varying in the amount of linguistic processing: vocal picture naming while ignoring distractor words (picture-word interference, PWI); vocal colour naming while ignoring distractor words (Stroop); and manual object discrimination while ignoring spatial position (Simon task). All three tasks had congruent and incongruent stimuli, while the PWI and Stroop tasks also had neutral stimuli. Analyses focusing on common activation across tasks identified a portion of the dorsal anterior cingulate cortex that was active in incongruent trials for all three tasks, suggesting that this region subserves a domain-general attentional control function. In the language tasks, this area showed increased activity for incongruent relative to congruent stimuli, consistent with the involvement of domain-general mechanisms of attentional control in word production. The two language tasks also showed activity in anterior-superior temporal gyrus. Activity increased for neutral PWI stimuli (picture and word did not share the same semantic category) relative to incongruent (categorically related) and congruent stimuli. This finding is consistent with the involvement of language-specific areas in word production, possibly related to retrieval of lexical-semantic information from memory. The current results thus suggest that in addition to engaging language-specific areas for core linguistic processes, speaking also engages the anterior cingulate cortex, a region that likely implements domain-general attentional control.

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7.1 Introduction

Accumulating evidence suggests that speakers need to engage attentional control for certain language processes (e.g., Ferreira & Pashler, 2002; Piai & Roelofs, 2013; Roelofs, 2002; Roelofs & Piai, 2011; Roelofs, 2003, 2008b). Attentional control refers to the regulatory and monitoring processes that ensure that our actions are in accordance with our goals, especially in the face of distraction (e.g., Posner & Petersen, 1990; Roelofs, 2003). For example, when planning a word or a multi-word utterance, speakers need to prevent interference from concurrent information in the environment, such as speech from an interlocutor or visual input from objects surrounding the referent. The object that one wants to refer to may have more than one name, in which case top-down regulation is needed to resolve the conflict between alternative responses. Attentional control also includes self-monitoring, through which speakers assess whether planning and performance are consistent with intent (e.g., Christoffels *et al.*, 2007; Hartsuiker & Kolk, 2001; Levelt *et al.*, 1999; Roelofs, 2004; van de Ven *et al.*, 2009). For example, Levelt (1989) suggests that "Message construction is controlled processing, and so is monitoring" (p. 21).

The present study was designed to address the extent to which these controlled processes may be language-specific or domain-general. In particular, we used functional magnetic resonance imaging (fMRI) to examine brain activity associated with performance in three tasks varying both in the amount of attentional control and in the amount of linguistic processing needed: vocal picture naming with distractor words (picture-word interference; PWI); vocal colour naming with distractor words (Stroop); and object discrimination using manual responding with spatial compatibility (Simon task). All three tasks contained stimuli with two dimensions that were either congruent or conflicting with each other, and required responding to a relevant dimension while ignoring an irrelevant one. Given that such conflict often leads to increases in error rates or the selection of an inappropriate response, people must constantly monitor and regulate their performance (e.g., Petersen & Posner, 2012; Posner & Petersen, 1990). Thus, these three tasks measure the extent to which attentional control is required to select a target response (e.g., Hommel, 2011; Petersen & Posner, 2012; Posner & Petersen, 1990; Roelofs, 2003), with conflicting stimulus dimensions in the incongruent condition increasing response time (RT) relative to neutral and congruent trials.

Attentional control functions have been extensively studied with the Stroop (Stroop, 1935; see also MacLeod, 1991) and Simon tasks (Simon & Small, 1969; see also Hommel, 2011). In the Stroop task, participants name the ink colour of words, with the ink colour being either congruent (e.g., *red* printed in red ink), incongruent (e.g., *blue* in red ink), or neutral (e.g., *dream* in red ink) with respect to the written word. In the Simon task, participants are instructed to respond to a colour or to the identity of an object with lateralised button presses (e.g., press right for a triangle and left for a square), and spatial congruency is manipulated either by presenting the object in the same (i.e., congruent) or opposite (i.e., incongruent) spatial position relative to the response. To examine attentional control functions in spoken word production, tasks such as Stroop

and PWI can be used. In the PWI task (Rosinski, 1977; see for review Glaser, 1992), participants name pictures while trying to ignore superimposed distractor words that are, for example, semantically related (e.g., a pictured car with distractor *bus*), semantically unrelated (e.g., pictured car, distractor *table*), or identical to the picture name (e.g., pictured car, distractor *car*). Thus, in addition to providing insight into lexical access, PWI is often seen as an experimental method that allows us to examine monitoring and regulation processes in spoken word production (e.g., Dhooge & Hartsuiker, 2011a; Glaser & Düngelhoff, 1984; Lupker, 1979; MacLeod, 1991; Roelofs, 2003). In the remainder of this article, we refer to the semantically related condition as *incongruent*, the unrelated as *neutral*, and the identical condition as *congruent*.

A network of brain areas has commonly been implicated in attentional control functions, as measured with the Stroop and Simon tasks (e.g., Fan *et al.*, 2003; Liu *et al.*, 2004; Peterson *et al.*, 2002). In particular, the effects of conflict in these tasks, i.e., more activity for incongruent relative to congruent stimuli, have been co-localised to the lateral prefrontal cortex (PFC) and the dorsal anterior cingulate cortex (ACC) (Fan *et al.*, 2003; Liu *et al.*, 2004). The dorsal ACC includes Brodmann areas 24 and 32 (Devinsky *et al.*, 1995; Paus, 2001; Ridderinkhof *et al.*, 2004), referred to as 'anterior' and 'mid' cingulate in the Automated Anatomical Labeling (AAL) template (Tzourio-Mazoyer *et al.*, 2002). The dorsal ACC is part of a frontoparietal network underlying domain-general attentional control (e.g., Barbey *et al.*, 2012; Duncan *et al.*, 2010; Niendam *et al.*, 2012), both at the task and response level (Aarts *et al.*, 2009). Although the exact function of the dorsal ACC within this network is still debated in the literature (e.g., conflict monitoring, Botvinick *et al.*, 2004; response selection, Awh and Gehring, 1999; top-down regulation of selection processes, Aarts *et al.*, 2008; Roelofs *et al.*, 2006; see also Alexander and Brown, 2011 for a recent proposal encompassing several other accounts), all theoretical frameworks acknowledge that the engagement of the dorsal ACC increases with incongruent relative to congruent or neutral stimuli.

In the past few years, significant progress has been made in delineating the neural substrates of the core language processes underlying speaking through the use of tasks such as picture naming, word generation, and word/pseudoword reading (for overviews see Indefrey & Levelt, 2004; Indefrey, 2011; Price, 2012). Despite this progress, the neural substrates associated with the processes of regulating and monitoring language production have remained relatively underspecified (cf. Indefrey, 2011; for recent advances, see Nozari *et al.*, 2011; Riès *et al.*, 2011), in part because the manipulations and comparisons within these tasks may not have been sensitive to attentional control functions. As concerns vocal utterances, the ACC plays an important role in controlling the initiation and suppression of non-verbal vocalisations in humans, such as laughing and crying (Jürgens, 2002). Because of its connections with lateral PFC, which is involved in broad aspects of top-down control (e.g., Paus, 2001; Petrides, 2005), it has been argued that the ACC has the appropriate characteristics to mediate the attentional control necessary for producing language (e.g., Roelofs, 2008b). Evidence for this proposal comes, for example, from a

review of two decades of language production neuroimaging research, indicating a critical role for the dorsal ACC during word selection in the context of non-target words (Price, 2012).

Despite this evidence, some important questions about the role of the dorsal ACC in language production have remained unanswered. In their meta-analysis of neuroimaging studies on word production, Indefrey and Levelt (2004) identified the mid-cingulate (part of the dorsal ACC more commonly defined) as one of the brain areas that are active in all production tasks examined (i.e., picture naming, word generation, and word/pseudoword reading). This suggests that the dorsal ACC may implement a production-general function (i.e., regulation and monitoring) rather than making a specific contribution to core language production processes (i.e., conceptual preparation, lexical selection, and word-form encoding). However, whether the production-general contribution of the dorsal ACC is also domain-general (i.e., also engaged outside the language domain) could not be assessed in the meta-analysis of Indefrey and Levelt. Moreover, it is still unclear whether regulation and monitoring processes in word production, as measured by the PWI task, involve the dorsal ACC. The first study to report ACC activity in PWI compared categorically related (incongruent) picture-distractor pairs with a control picture-distractor pair (i.e., a string of Xs) (de Zubicaray *et al.*, 2001). Note that the comparison between categorically related picture-word pairs and pictures paired with a string of Xs concerns a contrast between a word and nonword condition rather than between different word conditions (e.g., semantically related and unrelated words). Subsequent studies examining the contrast between categorically related and unrelated picture-word pairs (often referred to as the *semantic effect*) failed to observe modulations of ACC activity as a function of distractor type (de Zubicaray *et al.*, 2013; de Zubicaray & McMahon, 2009; Spalek & Thompson-Schill, 2008), whereas a study comparing phonologically related with unrelated pairs did obtain differences in orbital-frontal portions of the ACC (de Zubicaray *et al.*, 2002). Importantly, the portion of the ACC that was sensitive to distractor type in previous PWI studies (de Zubicaray *et al.*, 2001, 2002) does not correspond to areas previously associated with domain-general control, but rather to those observed in tasks involving the processing and control over emotion, reward, and pain (see Torta & Cauda, 2011) in the anterior portion of the ACC. Thus, it is unclear whether the system for attentional control in word production, commonly measured with the PWI task, is part of the same domain-general, attentional control system that has been implicated outside of language.

An additional goal of the present study was to determine whether common brain activation associated with lexical-semantic processing in word production can be found for the PWI and Stroop tasks. Although retrieval of words from long-term memory may rely on general processes for retrieving diverse information from memory, the storage of lexical-semantic knowledge has been mainly associated with left superior and middle temporal cortex (see for overviews Indefrey & Levelt, 2004; Price, 2012). In an extensive lesion-deficit analysis concerning semantic errors in picture naming by individuals with

post-stroke aphasia, Schwartz et al. (2009) identified the left anterior temporal cortex as the brain area that is critically involved in mapping concepts onto words in production (i.e., conceptually driven 'lemma retrieval'). This anterior temporal area included the mid-temporal region identified by Indefrey and Levelt (2004) as being involved in conceptually driven word retrieval, providing converging evidence for the functional role assigned to this area. PWI studies have consistently revealed sensitivity of the left superior temporal gyrus (STG) and middle temporal gyrus (MTG) activity to experimental manipulations (de Zubicaray *et al.*, 2001, 2002, 2013; de Zubicaray & McMahon, 2009), but in Stroop studies, activity in left temporal cortex is generally absent (e.g., Banich *et al.*, 2000; Bench *et al.*, 1993). Despite these previous results, it seems reasonable to predict that both tasks might activate elements of the temporal cortex as the distracting information is lexical-semantic in nature.

To recapitulate, the present study was designed to elucidate the inconclusive evidence for the involvement of a domain-general control mechanism, possibly supported by the dorsal ACC, in language production. Furthermore, we also investigated language-specific activity in left superior and middle temporal cortex, areas shown to be consistently involved in lexical-semantic processes in language production (Indefrey & Levelt, 2004; Indefrey, 2011). We used three tasks that are known to require attentional control, but crucially two of them were language tasks with vocal responding (PWI and Stroop), whereas the third was a spatial congruency task requiring manual responding (Simon). By examining the activity in the dorsal ACC that is common to all three tasks, we aimed at identifying a domain-general portion of the cingulate cortex that is active with incongruent (i.e., more difficult) trials. If domain-general control is involved in language production, then such a common dorsal ACC area should be found. Furthermore, we also investigated the activity in the left superior and middle temporal cortex, areas shown to be consistently involved in lexical-semantic retrieval in language production (Indefrey & Levelt, 2004; Indefrey, 2011).

7.2 Experimental Procedure

Participants

Twenty-six young adults (mean age = 21.2 years, range = 18-29) from the pool of Radboud University Nijmegen participated in the experiment for monetary compensation or course credits. Participants gave written informed consent to their participation after being informed about the nature of the study. Three female participants were excluded from the analyses for the following reasons. One participant revealed having dyslexia after the data were acquired; for another participant, a technical failure caused an imprecision in the registration of the time parameters; one participant was discarded for excessive movement in the scanner ($>$ 6 mm). The remaining 23 participants (11 male) were right-handed, native speakers of Dutch with normal or corrected-to-normal vision, and no history of neurological or reading deficits.

Materials and design

Picture-word interference task. Forty pictures were selected from the picture database of the Max Planck Institute for Psycholinguistics, Nijmegen, together with their basic-level names in Dutch. The pictures belonged to ten different semantic categories with four objects pertaining to each category. All pictures were white line drawings on a black background. The pictures subtended between 1° and 1.3° of the participant's visual angle. A list of the materials can be found in Appendix A.8. Three picture-word conditions were created. In the incongruent (categorically related) condition, each target picture was combined with a distractor word from the same semantic category (i.e., the distractor words were the names of the other category-coordinate pictured objects from our materials). For the neutral (categorically unrelated) condition, the pictures were recombined with the names of the pictures from the other semantic categories. Finally, in the congruent condition, the distractor words were the Dutch name of the pictures. Thus, all distractor words belonged to the response set and distractor type was varied within participants and within items. Each picture appeared once in each condition, totalling 40 trials per condition. The distractors were presented in font Arial size 30 in white, centred on the picture. The picture-word trials were randomised using Mix (van Casteren & Davis, 2006), with one unique list per participant. Participants were instructed to name the picture and to ignore the distractor word.

Stroop task. All words were presented in red, green, and blue font. There were three Stroop conditions: congruent, incongruent, and neutral. In the incongruent condition, the colour words (*red*, *green*, and *blue*) were displayed in an incongruent ink colour (e.g., *red* was presented in green and in blue, etc.). In the neutral condition, the Dutch words *taak* ('task'), *droom* ('dream'), and *klant* ('client') appeared five times in each ink colour. In the congruent condition, each colour word appeared in its corresponding ink colour. Each word appeared 15 times in each condition, totalling 45 trials per condition. The Stroop stimuli were presented in the centre of the screen in Arial font size 20, subtending between 1° and 1.3° of the participant's visual angle. The trials were randomised using Mix, with one unique list per participant. Participants were instructed to name the ink colour of the words.

Simon task. A square and a triangle were used as white line drawings presented on a black background, subtending about 3° of the participants' visual angle. Half of the participants were instructed to press a button with their left index finger in response to squares and another button with their right index finger to triangles. The other half of the participants received the opposite shape-button press mapping. Each shape appeared 33 times to the left of a centred fixation cross and 33 times to the right, yielding 66 congruent- and 66 incongruent-location trials. Note that this task lacked a neutral condition as this is not typically employed within this task. All 132 trials were randomised using Mix, with one unique list per participant. For the Simon task, two button boxes were resting on the participant's body, one near each hand.

Procedure and apparatus

Outside the scanner, participants read the instructions and were familiarised with the pictures and the names to be used in the experiment. Both speed and accuracy were emphasised for all three tasks. Next, participants practised each task with eight trials (PWI and Stroop) or 14 trials (Simon) in the same order they would perform them in the scanner, i.e., PWI, Stroop, Simon task. For the PWI task, two line drawings (heart and star) were selected as practice items. For the Stroop and Simon tasks, the same items were used for the practice and experimental sessions.

The presentation of stimuli (screen resolution 1024x768x32, 60 Hz refresh rate) and the recording of responses were controlled by Presentation Software 14.1 (Neurobehavioral Systems, Albany, CA). A noise-cancelling microphone, placed above the participant's mouth, was connected to the Presentation computer, enabling the recording of vocal responses and the measurement of vocal response latencies. The experiment started with the PWI task. A prompt on the screen indicated the end of one task and the beginning of the next task, with the instructions presented once more for 20 s. The Stroop task followed the PWI task, and the Simon task was performed last. For all three tasks, a trial started with the presentation of a fixation cross in the centre of the screen for 500 ms. Next, the stimulus was displayed for 1 s. For PWI and Stroop stimuli, they were displayed in the centre of the screen. For the Simon task, the stimuli were presented either to the right or to the left of the fixation cross, depending on the Simon condition of the trial. A black screen followed for the duration of the jitter period (varying between 2.4 and 6 s, following a normal distribution, randomly assigned to each trial). The registration of the vocal and manual responses started as soon as the stimuli were displayed and lasted until the next trial started. For each task, the stimuli were presented in three blocks with breaks of 20 s between blocks.

Data acquisition

Participants were scanned with a 1.5-T Siemens Avanto Scanner with a 32-channel head coil. For the acquisition of the functional data, we used a parallel-acquired inhomogeneity-desensitized fMRI sequence (Poser *et al.*, 2006), which is a multiecho echo-planar imaging sequence that reduces image artefacts and is therefore suitable for acquiring data of participants while they speak. In this sequence, the images are acquired at multiple time echoes (TEs) following a single excitation. The time repetition (TR) used was 2.31 seconds, with the five TEs acquired at 8.3, 27.6, 37, 46, and 55 ms (echo spacing = 0.5 ms, flip angle = 80°). Each volume comprised 36 slices of 3 mm thickness (ascending slice acquisition, voxel size = 3.5 x 3.5 x 3 mm^3, slice gap = 17%, field of view (FOV) = 224 mm, matrix = 64 x 64). GRAPPA parallel imaging was used (acceleration factor = 3). Functional scans were acquired in one run. First, 30 volumes were acquired and used for weight calculation of each of the echoes (pre-task volumes), followed by the three tasks one after the other.

For the anatomical MRI, T1-weighted images were acquired using a magnetization-

prepared, rapid-acquisition gradient echo sequence (MPRAGE; TR = 2.25 s, TE = 2.95 ms, echo spacing = 8.7 ms, flip angle = 15°). We acquired 176 sagittal slices (isotropic voxel size = 1 mm^3, FOV = 256 mm, matrix = 256 x 256).

Behavioural data analysis

For each trial of the PWI and Stroop tasks, the experimenter evaluated the participants' vocal responses. Trials that contained a disfluent response, a wrong pronunciation of the word, or a wrong response word were coded as errors and subsequently excluded from the statistical analyses of the naming RTs. Errors in the Simon task were also excluded from the statistical analysis of the manual RTs. Vocal RTs shorter than 200 ms and manual RTs shorter than 100 ms were also excluded from the analyses. RTs were submitted to by-participant (F_1) analyses of variance (ANOVA) for the Simon and Stroop tasks separately, and additionally to by-item (F_2) ANOVA for the PWI task, with stimulus type (neutral, incongruent, congruent) as the independent variable. Planned contrasts were examined with paired t-tests (two-tailed). Errors were submitted to logistic regression analyses. For the relevant contrasts (i.e., incongruent vs. congruent, incongruent vs. neutral), 95% confidence intervals (CI) around the mean difference are reported, as well as Cohen's d (a measure of effect size), calculated as the difference between two conditions divided by the square root of the averaged variance of the three conditions (Cumming, 2012). Due to technical failures, vocal RTs were not registered for six participants and manual RTs were not registered for one participant (errors were registered). Thus, the statistical analyses of the vocal responses comprised 17 participants and the analyses of the manual responses comprised 22 participants.

fMRI data preprocessing

The preprocessing steps were conducted using Matlab and SPM8. First, all volumes were realigned to the first volume and re-sliced. Then the five echoes of each volume were combined to yield one volume per TR using an in-house Matlab script (see for details Poser *et al.*, 2006). For each voxel, optimal weighting for the five echoes were calculated from the 30 pre-task volumes, and the weighting values were applied to the rest of the functional volumes resulting in one volume per TR. Then these images were slice-time corrected to the first slice. Means of the functional images were co-registered with the participant's anatomical volume. Finally, the functional and structural images were spatially normalised to Montreal Neurological Institute (MNI) space and smoothed (3D isotropic Gaussian smoothing kernel, full-width at half-maximum = 8 mm).

fMRI data analysis

Statistical analyses were performed within a general linear model (GLM) framework. For the analysis on individual participants' data, the model included eight regressors time-locked to the onset of each condition of each task (PWI incongruent, PWI neutral, PWI congruent, Stroop incongruent, Stroop neutral, Stroop congruent, Simon incongruent, and Simon congruent), one regressor for trials in which an error was made, and one re-

gressor to model the intra- and inter-task period. The onsets of each event were modelled as a gamma response, or stick-function (i.e., duration = 0) temporally convolved with the canonical hemodynamic response function along with the first temporal derivative. The model also included the six motion parameters and their first derivatives to account for residual movement-related artefacts. Since participants were overtly producing the words during the PWI and Stroop tasks, we specifically included the first derivatives of the motion parameters to account for signals that might be affected by sudden movements due to overt responses. A high pass filter was implemented (1/128 Hz cutoff) to account for slow drifts of the signal. The effects were estimated with a subject-specific fixed-effects model. We also modeled the RT as durations for each of the trials, but given that the results were quite similar to the ones reported below and we did not have the RTs for all participants, these results are not reported here.

Specific contrasts of interest were calculated for each participant and these contrast images were used as random variables on the group level. All clusters reported as significant had voxels thresholded at $p \leq .001$ (uncorrected), with the cluster-size statistics thresholded at $p \leq .05$ (family-wise error corrected) (Hayasaka & Nichols, 2003). First, we looked into areas that were significant in a whole-brain analysis. Since we were interested in domain-general activations, we localised shared areas that were active in all three tasks. For this aim, ANOVAs were performed on participants' individual contrast images with task and stimulus type as independent variables. We then conducted a "conjunction analysis" by identifying overlapping voxels that were above the threshold (voxel level $p \leq .001$, uncorrected) in each of the incongruent condition of all three tasks. For the linguistic-vocal tasks, images of each stimulus type were contrasted for each task separately using paired t-tests on the group level.

ROI analyses. Given our interest in the involvement of dorsal ACC, STG and MTG, a region of interest (ROI) analysis was performed by restricting our search volume within these ROIs defined anatomically using the AAL template (Tzourio-Mazoyer *et al.*, 2002). Furthermore, we were interested in the specific part of the dorsal ACC that was active during the conflict trials in all three tasks. For this, a conjunction analysis was performed within the bilateral cingulate cortices in the same way as reported above. The dorsal portion of the cingulate cortex that was commonly active in all three incongruent conditions, as shown in this conjunction analysis, was selected as the functional Cingulate ROI. To determine the involvement of this specific Cingulate ROI in the tasks separately, the beta weights from the functional Cingulate ROI were extracted and averaged for each participant and condition separately using the MarsBar toolbox (Brett *et al.*, 2002). Paired t-tests were used to test the conflict conditions in a pair-wise fashion for each task separately. Since we had an a priori hypothesis that the congruent conditions would elicit the least conflict, one-tailed tests were used.

For the linguistic-vocal tasks, the ROI analyses comprised left superior and middle temporal cortex (Indefrey & Levelt, 2004), according to the AAL template. The Stroop task showed a significant effect for incongruent > congruent condition in the left

temporal cortex. To observe activity differences between conditions for the PWI task in this area, we extracted averaged beta values of each PWI condition from this functional ROI for each participant using MarsBar. Paired *t*-tests (two tailed) were then used to test the conditions in a pair-wise fashion for the PWI task.

7.3 Results

7.3.1 Behavioural data

Table 7.1 presents the mean RTs and standard deviations for correct responses and the error rates as a function of stimulus type and task.

Table 7.1: Mean response time (M) and standard deviation (*sd*) in milliseconds, and percent error (E%) as a function of stimulus type in each task. Mean and standard deviation calculated over participants' single-trial data. PWI = picture-word interference.

	PWI			Stroop			Simon		
stimulus type	M	*sd*	E%	M	*sd*	E%	M	*sd*	E%
incongruent	971	171	5.3	852	152	2.9	508	146	5.9
congruent	853	145	2.9	759	127	0.7	464	145	3.2
neutral	946	163	4.9	794	129	0.6			

Errors. Table 7.2 presents the results of the logistic regression analysis on the errors. In sum, in the PWI task, errors were more likely in the incongruent than in the congruent condition but equally likely in the neutral condition, and more likely in the neutral than in the congruent condition. In the Stroop task, errors were more likely in the incongruent than in the congruent and in the neutral conditions, but equally likely in the neutral and congruent conditions. Finally, in the Simon task, errors were more likely in the incongruent than in the congruent condition.

RTs. Table 7.3 presents the results of the main effects of stimulus type, which was statistically significant for all three tasks. Table 7.4 presents the results of the pair-wise comparisons of condition for the three tasks. In sum, for all three tasks, RTs in the incongruent condition were longer than in the congruent and neutral (PWI and Stroop) conditions. Vocal RTs were also longer in the neutral than in the congruent condition.

7.3.2 fMRI data

Cross-domain activity. Areas that were commonly activated by incongruent stimuli in all three tasks in the whole-brain analysis are shown in Table 7.5, Figure 7.1(A) and Figure 7.2. The incongruent stimuli in all three tasks commonly activated the cerebellum (bilaterally), a large cluster in left Rolandic operculum and STG (Figure 7.2), and the

Table 7.2: Results of the logistic regression analysis on the errors for the three tasks. A dash indicates equal log-odds. coeff = coefficient; con = congruent; inc = incongruent; neu = neutral; PWI = picture-word interference.

contrast	log-odds	*β coeff*	*S.E.*	*Wald Z*	*p*
		PWI			
inc - con	1.9	.7	.3	2.5	.012
inc - neu	-	.1	.2	.4	.694
neu - con	1.8	.6	.3	2.2	.031
		Stroop			
inc - con	4.1	1.4	.4	3.3	.001
inc - neu	4.7	1.6	.5	3.4	.001
neu con	-	.2	.5	.3	.781
		Simon			
inc - con	1.9	.6	.2	3.4	.001

Table 7.3: Results of the analyses of variance on response times for the main effect of stimulus type in the picture-word interference, Stroop, and Simon tasks. For the picture-word interference (PWI) task, F_1 and F_2 are shown side-by-side, separated by the slash.

main effect stimulus type	*F*	df	*p*
PWI	41.4 / 103.2	2,32 / 2,78	$< .001$
Stroop	50.6	2,32	$< .001$
Simon	72.3	1,21	$< .001$

dorsal ACC (Figure 7.1(A)). Furthermore, in line with the whole brain analysis, two peaks of activity were observed in the dorsal ACC (BA 24; MNI: -4, 12, 36; and BA 32; MNI: 4, 18, 36) in the Cingulate ROI analysis, shown in the lower part of Table 7.5.

Note that ideally, analyses would have targeted regions showing increased BOLD responses for the incongruent relative to the congruent conditions across all three tasks. However, this analysis proved to be untenable in the present investigation as the BOLD responses in the dorsal ACC in the Simon task were already elevated in both congruent and incongruent conditions (see below), preventing us from detecting regions showing increased activity for the incongruent relative to the congruent condition in this task. Thus, we were not able to detect brain areas that were commonly modulated by stimulus type (i.e., incongruent > congruent) across all three tasks. Importantly, the cross-task conjunction of incongruent conditions still entails a contrast, i.e., versus a low-level baseline. Hence, with this contrast, we detect the activity from the most difficult condition in all three tasks relative to this low-level baseline. This is comparable to the approach taken by Indefrey and Levelt (2004) in their meta-analysis, where activity common to different

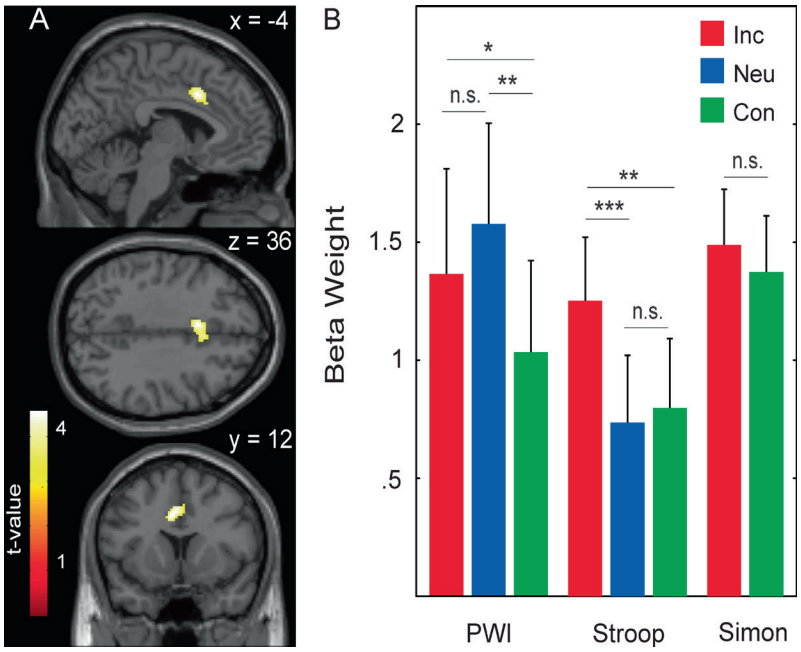

Figure 7.1: **(A)** Activity common to incongruent stimuli in the PWI, Stroop, and Simon tasks in the anterior cingulate cortex (BA 24; peak MNI: -4, 12, 36; and BA 32; peak MNI: 4, 18, 36). **(B)** Averaged beta weights of active voxels in the anterior cingulate cortex (shown in A) as a function of task and stimulus type. Inc = incongruent; Neu = neutral; Con = congruent; n.s. = non-significant. Error bars represent the standard error of the mean. p-values: * $\leq .05$, ** $\leq .01$, *** $\leq .005$.

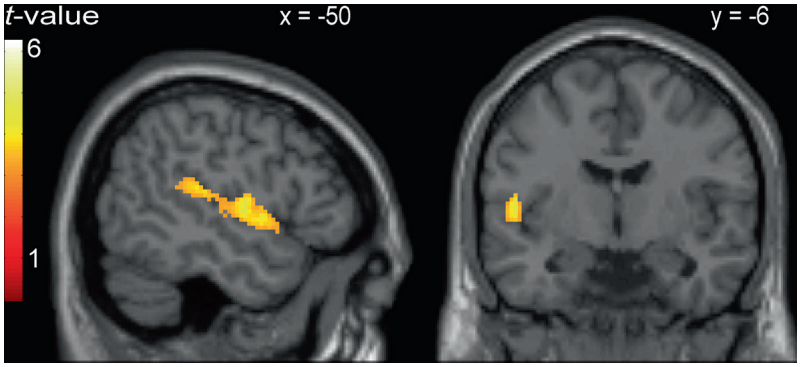

Figure 7.2: Activity common to incongruent stimuli in the PWI, Stroop, and Simon tasks in a cluster comprising left Rolandic operculum (BA 22; peak MNI: -50, -6, 4) and left superior temporal gyrus.

Table 7.4: Results of the pair-wise comparisons of response times between conditions for the picture-word interference (PWI), Stroop, and Simon tasks. For the PWI task, t_1 and t_2 and respective p-values are shown side-by-side, separated by the slash. CI = confidence interval; diff = difference in milliseconds; con = congruent; inc = incongruent; neu = neutral.

contrast	diff	t(df)	p	95% CI	d
		PWI			
inc - con	118	7.4 (16) / 13.7 (39)	$< .001$ / $< .001$	[87, 158]	.74
inc - neu	25	3.2 (16) / 2.4 (39)	.005 / .019	[10, 47]	.16
neu - con	93	6.1 (16) / 12.5 (39)	$< .001$ / $< .001$	[61, 127]	.58
		Stroop			
inc - con	93	8.1 (16)	$< .001$	[72, 124]	.68
inc - neu	58	6.2 (16)	$< .001$	[42, 84]	.43
neu con	35	5.3 (16)	$< .001$	[21, 49]	.25
		Simon			
inc - con	44	8.5 (21)	$< .001$	[34, 56]	.31

production tasks was detected by means of a comparison to a low-level baseline.

Figure 7.1(B) shows the mean beta weights extracted for each stimulus type in the three tasks from the Cingulate ROI, which was generated from the conjunction of the incongruent conditions across all three tasks. In the Stroop task, dorsal ACC activity was higher with incongruent than with congruent stimuli, $t(22) = 2.61$, $p = .008$; and higher with incongruent than neutral stimuli, $t(22) = 3.02$, $p = .003$; but similar for neutral and congruent stimuli, $t(22) < 1$. In the PWI task, dorsal ACC activity was higher with incongruent than with congruent stimuli, $t(22) = 1.99$, $p = .030$; and higher with neutral than congruent stimuli, $t(22) = 2.87$, $p = .009$; but similar for neutral and incongruent stimuli, $t(22) = 1.43$, $p = .083$. In the Simon task, elevated dorsal ACC activity did not differ between the incongruent and congruent conditions, $t(22) < 1$. The same pattern of activity was observed in the beta weights when we constrained the analyses to the 17 participants for whom RT data was available.

Language-specific activity

When testing for differences in brain activation between conditions for each task separately with the paired t-tests, only the Stroop task yielded significant results for the contrasts incongruent > congruent and incongruent > neutral. These results are presented in Table 7.6 and in Figure 7.3(A). In the whole-brain analysis, shown in the upper part of Table 7.6, both conflict contrasts (i.e., incongruent vs. neutral and incongruent vs. congruent) showed increased activity in the right inferior frontal gyrus. In the Cingulate ROI analysis, shown in the lower part of Table 7.6, dorsal ACC activations were also increased for incongruent stimuli relative to neutral and congruent stimuli. Interestingly, in the Left Temporal ROI analysis, shown in Figure 7.3(A), activity in left STG was

Table 7.5: Statistically significant activations in the whole-brain and ROI analyses for the conjunction of the PWI, Stroop, and Simon tasks. Voxels thresholded at $p = .001$. For each cluster, coordinates are given for the maximally activated voxel and up to two local maxima more than 8 mm apart. Cluster size corresponds to the number of voxels (2x2x2 mm) comprising the cluster. The mid cingulate in the AAL template is part of the dorsal ACC as usually defined (Devinsky *et al.*, 1995; Paus, 2001; Ridderinkhof *et al.*, 2004). Cor = Family-wise error (FWE) corrected on the cluster-level; g. = gyrus; l = left; r = right; supplem. = supplementary; unc = uncorrected. * Voxel $p < .05$ also when FWE-corrected on the voxel level.

cluster p(cor)	cluster size	voxel t value	voxel z value	voxel p(unc)	MNI space x,y,z (mm)	anatomical region (AAL)
			whole-brain analysis			
.000	2720	6.24	5.83	<.001*	30, -54, 28	r cerebellum
		6.00	5.64	<.001*	-28, -56, -26	l cerebellum
		5.08	4.84	<.001*	-18, -56, -22	l cerebellum
.001	625	4.51	4.34	<.001	-50, -6, 4	l Rolandic operculum
		4.11	3.98	<.001	-46, -30, 16	l superior temporal g.
		4.03	3.90	<.001	-48, 4, 0	l superior temporal g.
.041	260	4.55	4.37	<.001	-4, 12, 36	mid cingulate gyrus
		4.13	4.00	<.001	0, 12, 46	supplem. motor area
		3.96	3.84	<.001	-2, 4, 50	medial frontal gyrus
			anatomical ROI analysis			
.009	187	4.55	4.37	<.001*	-4, 12, 36	mid cingulate
		3.89	3.78	<.001*	4, 18, 36	mid cingulate

also increased for incongruent relative to congruent stimuli. Note that this left STG ROI area (MNI -50, 0, -12 and -46, -10, -12) is slightly more ventral than the left STG area (MNI -46, -30, 16 and -48, 4, 0) that was identified by the conjunction of the incongruent conditions in all three tasks. That is, the left STG ROI area is not activated by the Simon task, which suggests that its activation is language-specific.

To examine language-specific activity in the PWI task, the averaged beta weights within this left STG cluster were extracted, which is shown in Figure 7.3(B). Activity in left STG was higher with neutral than with congruent (identical) stimuli, $t(22) = 2.31$, $p = .030$; and higher with neutral than incongruent (categorically related) stimuli, $t(22) = 2.87$, $p = .009$; but similar for congruent and incongruent stimuli, $t(22) < 1$. Importantly, activity in this left STG cluster was not significantly increased from baseline for the Simon task (incongruent: beta weight = .008, $t(22) < 1$; congruent: beta weight = .37, $t(22) = 1.73$, $p = .097$); nor did it differ between incongruent and congruent conditions, $t(22) < 1$. The same pattern of activity was observed in the beta weights when we constrained the analyses to the 17 participants for whom RT data was available.

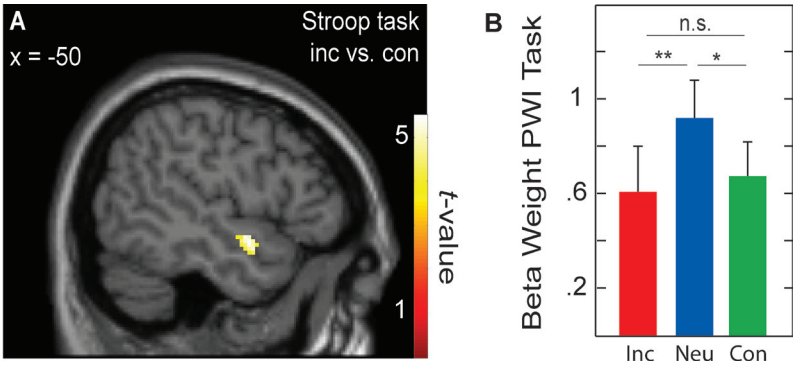

Figure 7.3: **(A)** Active voxels for incongruent versus congruent in the Stroop task (BA 38; peak MNI: -50, 0, -12; and -46, -10, -12). **(B)** Averaged beta weights of active voxels in (A) in the PWI task as a function stimulus type. Inc = incongruent; Neu = neutral; Con = congruent; n.s. = non-significant. Error bars represent the standard error of the mean. p-values: * $\leq .05$, ** $\leq .01$.

7.4 Discussion

In the present study, we compared three control-demanding tasks, two of which had linguistic stimuli requiring vocal responding (Stroop and PWI), and the third had visual-spatial stimuli requiring manual responding (Simon task). Participants responded to congruent and incongruent stimuli in all three tasks, and in the Stroop and PWI tasks to neutral stimuli as well. Behaviourally, RTs were longer for incongruent than for congruent stimuli in all three tasks. Furthermore, in the linguistic-vocal tasks, RTs were longer for neutral than congruent stimuli. These results are in line with previous literature for all three tasks (see for reviews PWI: Glaser, 1992; Stroop: MacLeod, 1991; Simon: Hommel, 2011).

Regarding the neuroimaging data, an analysis was performed to identify areas showing increased BOLD responses common to the incongruent condition in all three tasks (cross-domain activation). The areas identified by this conjunction analysis were bilateral cerebellum, left Rolandic operculum extending to the left STG, and the dorsal ACC.

Top-down control of task performance has been associated with a frontoparietal network of brain areas, including lateral prefrontal cortex, anterior insula/frontal operculum, pre-supplementary motor area (SMA) and ACC, and regions in and around the intraparietal sulcus (e.g., Barbey *et al.*, 2012; Dosenbach *et al.*, 2006; Duncan *et al.*, 2010; Niendam *et al.*, 2012; Petersen & Posner, 2012; Power *et al.*, 2011). So our finding of common activation in left operculum, SMA, and ACC across incongruent conditions in all tasks is in line with the evidence that a domain-general attentional control system is implemented by frontoparietal areas. Given our interest in the involvement of the cingulate cortex in spoken word production, as discussed in the introduction, we further

Table 7.6: Statistically significant activations for the Stroop task in the whole-brain and ROI analyses (cingulate and left superior/middle temporal cortex). Voxels thresholded at $p = .001$. For each cluster, coordinates are given for the maximally activated voxel and up to two local maxima more than 8 mm apart. Cluster size corresponds to the number of voxels (2x2x2 mm) comprising the cluster. The mid cingulate in the AAL template is part of the dorsal ACC as usually defined (Devinsky *et al.*, 1995; Paus, 2001; Ridderinkhof *et al.*, 2004). Cor = Family-wise error (FWE) corrected on the cluster-level; g. = gyrus; IFG = inferior frontal gyrus; l = left; r = right; sup. = superior; supplem. = supplementary; unc = uncorrected. * Voxel $p < .05$ also when FWE-corrected on the voxel level.

cluster p(cor)	cluster size	voxel t value	voxel z value	voxel p(unc)	MNI space x,y,z (mm)	anatomical region (AAL)
			whole-brain analysis			
incongruent versus congruent						
.000	528	5.70	4.42	<.001	36, 22, -14	r IFG pars orbitalis
		4.24	3.58	<.001	38, 28, 2	r IFG pars triangularis
.025	211	5.57	4.36	<.001	12, 10, 8	r caudate
		4.03	3.45	<.001	14, 12, -6	r putamen
		3.84	3.33	<.001	16, -6, 10	
incongruent versus neutral						
.007	294	5.41	4.27	<.001	32, 16, -14	r insula
		4.24	3.59	<.001	44, 20, 6	r IFG pars triangularis
		4.01	3.44	<.001	34, 26, 0	r insula
.001	461	5.37	4.25	<.001	4, 28, 30	mid cingulate
		4.84	3.95	<.001	8, 18, 46	r supplem. motor area
		4.79	3.92	<.001	12, 32, 26	anterior cingulate
			anatomical ROI analysis			
incongruent versus congruent						
.025	88	4.18	3.55	<.001	0, 30, 26	anterior cingulate
		3.90	3.36	<.001	-4, 30, 22	anterior cingulate
		3.86	3.33	<.001	4, 24, 30	mid cingulate
.042	65	5.48	4.31	<.001*	-50, 0, -12	l sup. temporal g.
		3.59	3.15	.001	-46, -10, -12	l superior temporal
incongruent versus neutral						
.000	370	5.37	4.25	<.001*	4, 28, 30	mid cingulate
		5.11	4.11	<.001*	6, 34, 28	anterior cingulate
		4.79	3.92	<.001*	12, 32, 26	anterior cingulate

examined activity in this area for the language tasks.

7.4.1 Cross-domain anterior cingulate cortex activity in language tasks

An extensive meta-analysis of the cingulate cortex has linked different portions of this area to different behavioural domains, i.e., attention, action, emotion, language, memory, and pain (Torta & Cauda, 2011). In this meta-analysis, two adjacent regions were shown to be involved in all six domains examined, suggesting the exercise of a general function that is commonly called upon by performance in multiple tasks. Notably, the portion of the cingulate cortex where we observed the common activity across our tasks is a part of this multi-domain area identified by the meta-analysis. The activity we observed in the domain-general portion of the cingulate cortex was common to the incongruent condition of all three tasks, thus, independent of the response modality and nature of the stimuli (linguistic vs. non-linguistic). Therefore, the most plausible account for our results is that this activity reflects a domain-general attentional control function, a proposal that is also in line with the functional interpretation of the frontoparietal network of brain areas (e.g., Barbey *et al.*, 2012; Dosenbach *et al.*, 2006; Duncan *et al.*, 2010; Niendam *et al.*, 2012; Petersen & Posner, 2012). As indicated previously in the introduction, researchers have found no agreement about what exactly this domain-general function of the ACC is (e.g., conflict monitoring, top-down regulation) but at least our result shows that the activity in this region is present when controlled responses are required in both linguistic and non-linguistic tasks.

The evidence for the involvement of the dorsal ACC in the PWI task has thus far remained inconclusive in the literature. To address this issue, we examined the portion of the dorsal ACC that was activated across tasks for modulations in activity as a function of stimulus type in the language tasks (Stroop and PWI). In the Stroop task, activity was higher for incongruent than for neutral and congruent colour words. In the PWI task, activity was higher for incongruent and neutral picture-word pairs relative to congruent pairs. These results provide the first direct neuroimaging evidence for the involvement of a domain-general portion of the cingulate cortex in the control over spoken word production (for a comparison between Stroop and Simon tasks with manual responding see Liu *et al.*, 2004; Peterson *et al.*, 2002). Our results agree with the proposal of Roelofs and colleagues (e.g., Roelofs, 2003; Roelofs & Hagoort, 2002; Roelofs *et al.*, 2006), who argued for a regulation function of the ACC, in line with the evidence for a regulatory role of the ACC in nonverbal vocalisations (Aitken, 1981; Jürgens, 2002, 2009; Ploog, 1981). Moreover, our results also agree with the recent proposal of Nozari, Dell, and Schwartz (2011), who suggested that the ACC is implicated in self-monitoring in language production, in line with the ACC conflict-detection view (Botvinick *et al.*, 2004). The present results do not allow us to adjudicate between the regulation and monitoring views, so future studies explicitly addressing this issue are needed.

Interference effects in behaviour and brain activity

We observed a discrepancy in the language tasks between the condition differences in

the RTs (incongruent > neutral > congruent) and the beta estimates in the dorsal ACC (see Figure 7.1). For the Stroop task, the incongruent condition led to an increased BOLD response relative to both the neutral and congruent conditions (incongruent > neutral = congruent), whereas for the PWI task, the incongruent and neutral conditions both had higher BOLD responses than the congruent condition (incongruent = neutral > congruent). Conflict, and thus the amount of conflict detected (Botvinick *et al.*, 2004) or the amount of top-down regulation needed (Roelofs *et al.*, 2006), is thought to be highest in the incongruent condition, followed by the neutral, and then the congruent condition. This pattern was clearly present in the RT data, but not in the neuroimaging data, even when the analyses of the neuroimaging data were constrained to the subjects for whom behavioural data was available. Based on this pattern, it could be argued that the present results do not agree with either the conflict monitoring or the top-down regulation views of ACC function.

The apparent discrepancy between RTs and ACC activity, however, can be resolved (and the theoretical views can be saved) if the magnitude of the conflict effects as evident in the RTs is taken into account. The largest RT effects in the PWI and Stroop tasks (> 58 ms on average) are also the effects being detected in the BOLD estimates for each task, whereas the contrasts from the smaller behavioural effects, i.e., on average 25 ms for incongruent vs. neutral in PWI and 35 ms for neutral vs. congruent in Stroop, resulted in no statistically significant differences in the BOLD response. The relatively small behavioural effect sizes may suggest that the discrepancy between the behavioural interference effects and the activity in dorsal ACC may well be a matter of low statistical power. Despite the lack of an exact parallel between condition differences in RTs and dorsal ACC activity, the present results support our claim that a domain-general attentional control mechanism in the dorsal ACC is engaged during spoken word production.

Anterior cingulate cortex activity in picture-word interference studies

As mentioned in the introduction, only one PWI study had observed increased dorsal ACC activity for categorically related picture-word stimuli (equivalent to our incongruent condition) relative to a low-level control condition (de Zubicaray *et al.*, 2001), whereas subsequent PWI studies did not observe differential activity in this area for categorically related (incongruent) and unrelated (neutral) picture-word pairs (de Zubicaray *et al.*, 2013; de Zubicaray & McMahon, 2009; Spalek & Thompson-Schill, 2008). Similar to some of these previous results, we also did not observe activation differences in the dorsal ACC for categorically related relative to unrelated picture-word pairs. As discussed above, the difference in the amount of conflict between these two conditions may not have been large enough to give rise to detectable differences in brain activity. However, different from all previous studies, our design also included congruent picture-word pairs, for which conflict is absent. Relative to the congruent condition, conflicting picture-word pairs were associated with increased dorsal ACC activity, in line with the hypothesis that the ACC is involved in attentional control over word production (i.e., conflict monitoring or top-down

regulation). Previous fMRI investigations comparing categorically related picture-word pairs with no-conflict pairs (i.e., pictures paired with a string of Xs) observed activity in an orbito-frontal ACC area not previously associated with domain-general control (cf. de Zubicaray *et al.*, 2001; Torta & Cauda, 2011). Thus, our study provides evidence for the involvement of the dorsal ACC in control over word production.

7.4.2 Language-specific activity

Stroop task

The Stroop task has been well studied with fMRI, although the large majority of these studies have used manual responding (e.g., Banich *et al.*, 2000; Bench *et al.*, 1993; Liu *et al.*, 2004; see for a brief overview MacLeod & MacDonald, 2000), rather than vocal responding (e.g., Barch *et al.*, 2001; Brown *et al.*, 1999; Carter *et al.*, 1995). In our task, participants responded overtly to incongruent, neutral, and congruent stimuli. In line with previous literature using manual and vocal responding, an increased BOLD response in the dorsal ACC was observed for incongruent relative to congruent and colour-neutral words (e.g., Banich *et al.*, 2000; Barch *et al.*, 2001; Fan *et al.*, 2003). Moreover, right inferior frontal gyrus (rIFG) and insular activity was also increased for incongruent relative to neutral and congruent stimuli, which is also consistent with previous studies using manual responding (e.g., Floden *et al.*, 2011; Peterson *et al.*, 2002). Earlier studies have suggested that the rIFG is involved in inhibition (e.g., Aron *et al.*, 2004) or the detection of salient or task-relevant cues indicating the need for top-down regulation (e.g., Hampshire *et al.*, 2007). Our findings are compatible with both views. However, the literature suggests that the inhibition function implemented by rIFG is domain-general, whereas we observed activity in this area only related to a language task. This finding agrees with the view that inhibition is not necessarily engaged to resolve conflict but rather is optionally employed (Roelofs *et al.*, 2011a; Verhoef *et al.*, 2009).

In addition to the areas that were common to the Stroop contrasts (incongruent vs. congruent and incongruent vs. neutral), increased BOLD responses were also observed in right caudate and putamen for incongruent relative to congruent stimuli. This finding is in line with the evidence that caudate nucleus and putamen are among the primary subcortical areas that underlie attentional control (e.g., Aarts *et al.*, 2010; Wiecki & Frank, 2013), both at the task and response level (Aarts *et al.*, 2009). These results thus suggest that language production, like other motor tasks, engage a frontal-striatal network implicated in attentional control. Finally, we also observed increased BOLD responses in left anterior STG for incongruent relative to congruent stimuli, a less common finding in the literature (e.g., Fan *et al.*, 2003). We will elaborate on this left STG activation in the next section.

Picture-word interference task and left temporal cortex

For the left anterior STG area showing BOLD response differences in the Stroop task, activity was increased for neutral (categorically unrelated) relative to the incongruent

(categorically related) and congruent stimuli in the PWI task. The STG area we observed is located within the left anterior temporal lobe, a structure crucial for semantic memory (Binder *et al.*, 2009; Bonner & Price, 2013; Patterson *et al.*, 2007; Visser *et al.*, 2010), including the mapping of concepts onto words in production (Indefrey & Levelt, 2004; Schwartz *et al.*, 2009). Furthermore, our left temporal cortex activity is similar to a previous report of a PWI study also using categorically related and unrelated picture-word pairs (de Zubicaray *et al.*, 2013). In that study, the left MTG activity was also interpreted in terms of lexical-semantic memory (Indefrey & Levelt, 2004).

Previous fMRI studies investigating the categorically related condition either in comparison to the unrelated condition (de Zubicaray *et al.*, 2013; de Zubicaray & McMahon, 2009) or to a control condition (de Zubicaray *et al.*, 2001) have observed modulations in the BOLD signal in left STG and MTG as a function of picture-word type. For example, a recent fMRI study (de Zubicaray *et al.*, 2013) observed longer picture-naming RTs for related than unrelated stimuli, but a reduction in activity in left MTG for related relative to unrelated stimuli, similar to our finding of reduced activity in left STG for incongruent (i.e., categorically related) relative to neutral (i.e., unrelated) stimuli. In line with these findings, our results provide independent evidence of *increased* picture-naming RT and *decreased* activity in left temporal cortex for categorically related picture-word pairs relative to unrelated pairs. This finding is also in line with the magnetoencephalography results of Chapter 4, which used very similar stimulus materials as in the present fMRI study. In Chapter 4, responses from left middle temporal cortex between 300-500 ms after picture-word presentation were *smaller* for categorically related (and congruent) picture-word pairs relative to unrelated pairs. Importantly, the behavioural data showed the usual pattern of *longer* picture-naming RTs for related than unrelated stimuli.

How can we interpret this difference between RTs and brain responses for related and unrelated conditions in the PWI task? In order to name a picture, speakers have to retrieve its name from long-term memory. Upon picture presentation, activation from the pictured concept spreads through the lexical-semantic network, leading to the activation of a cohort of words that belong to the network (e.g., Abdel Rahman & Melinger, 2009b; Roelofs, 1992). Similarly, the distractor word also activates representations in this network. Crucially, in PWI, the picture activates the distractor word on related but not on unrelated trials. This "reverse priming" makes related distractors stronger competitors than unrelated ones (Roelofs, 1992). Such priming in the lexical-semantic memory system (e.g., Collins & Loftus, 1975; Roelofs, 1992) may explain why categorically (and semantically) related picture-word pairs show less brain activity in left temporal cortex relative to unrelated pairs (de Zubicaray *et al.*, 2013, Chapter 4, and the present results).

Although this account can explain why we observed reduced activity in the left STG, it requires an additional mechanism to account for the slowdown in naming associated with categorically related picture-word pairs. Such a mechanism has been proposed by Roelofs (1992), who presented computer simulations demonstrating that the semantic interference effect in RTs is explained by reverse priming and selection of a word only if its activation exceeds that of alternative words by a critical amount. Moreover,

the simulations by Roelofs et al. (2006) demonstrated that if the ACC is involved in enhancing the activation of a target concept until a corresponding word is selected, then the patterns of ACC activity in Stroop-like tasks (including those in the present study) can also be explained. Our fMRI results not only corroborate previous findings regarding left temporal cortex, for which the activation reflects priming in the lexical-semantic memory system, but also highlight the involvement of the dorsal ACC, especially when selection and monitoring processes are more demanding due to the co-activation of categorically related words.

7.4.3 Conclusions

The present study was designed to address whether a common neural-substrate might be engaged in the attentional control over linguistic and non-linguistic tasks with varying degrees of conflict. We observed activity in the dorsal ACC that was common to incongruent conditions of three different attentional control tasks, regardless of the response modality (vocal vs. manual) and nature of the stimuli (linguistic vs. nonlinguistic). This common activation suggests a domain-general substrate that is called upon by all three tasks. More focused analysis of this commonly-activated region of the dorsal ACC in the linguistic-vocal tasks showed that it was sensitive to more difficult (i.e., incongruent) relative to easier linguistic stimuli. Finally, in the picture-word interference task, increased activity was observed in left anterior superior temporal cortex for picture-word pairs that did not belong to the same semantic category relative to picture-word pairs that did, probably reflecting the extent to which categorically related words were co-activated through target and distractor cues. These results suggest that language production engages brain areas implementing domain-general mechanisms for attentional control, as well as areas related to core language processes, such as lexical-semantic retrieval.

CHAPTER 8

Summary and Discussion

In this dissertation, I examined in depth the hypothesis that lexical selection in spoken word production is a competitive process, i.e., that the selection process is hampered by the amount of activation of other word candidates in the lexical network. This competition was examined by measuring the amount of semantic interference in picture naming, an effect that is central to the debate of lexical selection in production. According to the competition hypothesis, words **compete for selection**. Recently, however, much debate has been fueled around the semantic interference effect. Two alternative hypotheses have been put forward, suggesting that the locus of the effect is *prior* to lexical selection (Dell'Acqua *et al.*, 2007) or *after* lexical selection, close to articulation onset (Finkbeiner & Caramazza, 2006a,b; Janssen *et al.*, 2008; Mahon *et al.*, 2007; Miozzo & Caramazza, 2003). In this dissertation, I investigated the evidence for each of these alternative hypotheses. In addition, I investigated the role of attentional control mechanisms in spoken word production. Below, I present a summary of the main findings of each chapter in relation to the semantic interference effect and discuss them in light of the theory of competitive lexical selection. Moreover, I provide a critical review integrating some of the present findings.

8.1 The Locus of Semantic Interference

8.1.1 A post-lexical selection locus of semantic interference?

In the context of picture-word interference, the response exclusion account proposes that the semantic interference effect emerges **after** lexical selection, close to articulation onset, due to production-ready responses occupying the articulatory buffer (e.g., Janssen *et al.*, 2008; Finkbeiner & Caramazza, 2006a,b). In Chapters 2 and 3, I closely examined two important pieces of evidence for this account.

In Chapter 2, semantic interference in immediate and delayed picture naming was assessed based on previous findings of Janssen et al. (2008). According to the lexical competition hypothesis, in delayed picture-naming, the picture name is selected in the absence of a competing distractor word, and therefore, no semantic interference effect is predicted. In contrast, according to the response exclusion hypothesis, semantic interference should be obtained in both immediate and delayed picture naming because the distractor needs to be excluded from the output buffer in both cases. In disagreement with the findings of Janssen et al. (2008), in three experiments, no semantic interference was observed in delayed naming (see also Mädebach *et al.*, 2011). These results are in line with the lexical competition hypothesis, but they challenge the response exclusion hypothesis.

In Chapter 3, I examined the hypothesis that distractor strength influences the likelihood that a distractor word enters the competition process with the picture name. Previous studies have shown that masked distractors can yield semantic facilitation in picture-word interference (Dhooge & Hartsuiker, 2010; Finkbeiner & Caramazza, 2006b). These results were interpreted as evidence for the response exclusion hypothesis: Only

consciously perceived distractors can enter the articulatory buffer, yielding the interference effect. If they are not consciously perceived, they will not occupy the buffer, and thus, priming will induce semantic facilitation. In contrast, I proposed that interference and facilitation effects of distractor words reflect whether or not distractors are strong enough to enter the competition process. Firstly, I showed that facilitation can be obtained with clearly visible distractors when co-activation is low. Secondly, I showed that interference can be obtained with masked (i.e., poorly visible) distractors when co-activation is high, suggesting that visibility in itself is not crucial for inducing interference. These results are in disagreement with the predictions of the response exclusion account (Finkbeiner & Caramazza, 2006b) that masked distractors should not enter the buffer (i.e., no interference effect predicted), whereas visible distractors should enter the buffer (i.e., interference rather than facilitation predicted). I argued that the polarity of these effects can be explained by the distractor strength hypothesis without the need to allude to conscious perception.

In Chapter 4, I used magnetoencephalography (MEG) to characterise brain activity associated with lexical activation and competition in spoken word production. Previous studies have argued that the combination of priming of the distractor by the picture (reverse priming) and of the picture by the distractor is incompatible with the finding that semantically related distractors yield interference in picture naming (e.g., Blackford *et al.*, 2012; Finkbeiner & Caramazza, 2006a). Crucially, until now, only a few electrophysiological studies have succeeded in identifying brain responses reflecting the interference from related distractors. This has been taken as evidence against the competition hypothesis. Chapter 4 addressed this issue. I observed that evoked brain activity in the left temporal cortex, peaking at approximately 400 ms, was larger for unrelated than for related picture-word pairs, and larger for unrelated than for identical picture-word pairs. These results are in line with findings from semantic priming (for review, see Kutas & Federmeier, 2011). Importantly, the induced activity in the left superior frontal gyrus, showed power increases in the 4-10 Hz range between 400-650 ms following the condition ordering of the naming RTs (i.e., related > unrelated > identical). Moreover, when the induced activity was time-locked to response onset, power was modulated between 400-200 ms before articulation onset. These results challenge the response exclusion hypothesis, which predicts that brain activity reflecting interference should not occur earlier than about 145 ms before speech onset (see Figure 1.4).

Beyond the present dissertation

Further work has also highlighted problems with the response exclusion hypothesis with respect to other empirical findings and with respect to inconsistencies in the architecture of the proposed mechanisms (Abdel Rahman & Melinger, 2009a; Abdel Rahman & Aristei, 2010; Hantsch & Mädebach, 2013; Hutson *et al.*, 2013; La Heij *et al.*, 2006; Mulatti & Coltheart, 2012; Roelofs *et al.*, 2011b, 2013; Roelofs & Piai, 2013; Starreveld *et al.*, 2013). In a study not presented in this dissertation, we have used WEAVER++ simulations to address other effects claimed to challenge the competition hypothesis. In particular, we

(Roelofs *et al.*, 2011b) have shown that the distractor-frequency effect (i.e., low-frequency distractors yield more interference than high-frequency distractors; Dhooge & Hartsuiker, 2010; Miozzo & Caramazza, 2003) is not in disagreement with the competition hypothesis, but is accounted for by an attentional mechanism that has long been part of the model's architecture (see Roelofs, 2005). Furthermore, we (Roelofs *et al.*, 2013) have also pointed to five findings from the word production literature that challenge the response exclusion hypothesis. To support our argument, we showed that WEAVER++ can successfully simulate these findings, indicating that they are in agreement with the competition account. Finally, it has been claimed that associative facilitation from colour-related words in the Stroop task (e.g., naming the ink colour green is faster if the word is 'lawn' relative to 'sky') is in disagreement with the competition hypothesis (Mahon *et al.*, 2012). However, Roelofs and Piai (2013) have pointed out that WEAVER++ successfully simulates the associative facilitation effect (reported in Roelofs, 2003). Roelofs and Piai (2013) also provided new WEAVER++ simulations of the facilitation findings.

In conclusion, on closer inspection, there is no clear evidence against the competition hypothesis. Rather, there is much evidence in its favour.

8.1.2 A pre-lexical selection locus of semantic interference?

In Chapters 5 and 6, I examined the claim that the semantic interference effect arises **before** lexical selection (Ayora *et al.*, 2011; Dell'Acqua *et al.*, 2007).

In Chapter 5, I used a dual-task procedure (i.e., the psychological refractory period paradigm) to examine the hypothesis of a pre-lexical selection locus of the semantic interference effect. Distractor interference effects were assessed at short (0,100 ms) and long (500, 1000 ms) stimulus onset asynchronies (SOAs) between a tone and the picture-word stimuli. In six experiments, interference effects of equal magnitude were obtained at short and long SOAs, regardless of the exact tasks used (picture-word interference, colour-word Stroop), stimulus materials, stimulus types (related, unrelated, congruent, neutral), number of tones (two or three), and (proportion of) SOAs (0, 100, 500, 1000 ms). In an additional study not presented in this dissertation (Piai & Roelofs, 2013), we reported another experiment showing interference effects of equal magnitude at short and long SOAs. These results are not compatible with the claim of Dell'Acqua et al. (2007) and Ayora et al. (2011) that the semantic interference effect emerges prior to lexical selection.

In Chapter 6, the hypothesis of a pre-lexical selection locus was tested using the electroencephalogram (EEG). Differences in the electrophysiological signal associated with distractor type effects were observed starting around 250 ms after stimulus onset. Using the time estimates proposed in Figure 1.4, this timing is in line with a locus of the distractor interference effects at a word planning stage (i.e., lexical selection), and thus, they do not support a pre-lexical selection locus.

In summary, the evidence that the semantic interference effect emerges prior to lexical selection is not supported by the present findings.

8.1.3 Conclusion

Much of the work in this dissertation has been based on previous findings that challenged the competition hypothesis. In particular, Chapter 2 was an attempt to replicate Janssen et al. (2008) and Chapter 5 was an attempt to replicate Dell'Acqua et al. (2007) and Ayora et al. (2011). In line with Mädebach et al. (2011), in Chapter 2, I showed that the findings of Janssen et al. (2008) could **not** be replicated. Similarly, in line with other studies (Kleinman, 2013; Piai & Roelofs, 2013; Schnur & Martin, 2012), in Chapter 5, I showed that the findings of Dell'Acqua et al. (2007) and Ayora et al. (2011) could **not** be replicated. Other challenges to the theory not addressed in this dissertation have also faced the problem of non-replication (see Abdel Rahman *et al.*, 2010; Lee & de Zubicaray, 2010, Rinus Verdonschot, personal communication).

The replicability of findings is of utmost importance for theory formation (e.g., Cumming, 2008, 2012; Cumming & Maillardet, 2006; Fisher, 1966; Kline, 2004), and replication is, in my opinion, a necessary condition for further theorising. The results of Chapters 2 and 5 illustrate this fact by showing how findings apparently challenging a theory are of little importance if they never prove to be due to more than chance. At other times, challenges to a theory remain questionable if the findings can be accounted for by alternative explanations, as argued in Chapter 3 (see also Roelofs *et al.*, 2011b).

Taken together, the findings of Chapters 2 to 6 support the hypothesis that the semantic interference effect emerges during word planning stages, and in particular during lexical selection, in line with the theory of competitive lexical selection.

8.2 Beyond the Locus of Semantic Interference

In the following, I will summarise and critically review the main findings of this dissertation concerning other issues related to word production and discuss how they can be understood in relation to each other and in a broader context.

8.2.1 The interplay between lexical memory and attentional control

In Chapter 7, I used functional magnetic resonance imaging (fMRI) to shed light on the nature of control processes operating in response selection in word production. I compared brain activity associated with three attention-demanding tasks varying in the amount of linguistic processing: the colour-word Stroop task, the picture-word interference task, and the spatial-congruency Simon task. A portion of the anterior cingulate cortex was commonly active for incongruent stimuli in all three tasks. These results suggest that this region subserves a domain-general attentional control function. For the language tasks in particular, activity in this area increased for semantically related relative to identity related stimuli, consistent with the involvement of domain-general mechanisms of attentional control in word production. Furthermore, a region of the anterior-superior temporal

gyrus showed language-specific activity, with activation increases for semantically unrelated relative to semantically related and identical picture-word stimuli. These findings were interpreted with respect to retrieval of lexical-semantic information from memory.

The results of the fMRI study reported in Chapter 7 corroborate the findings from Chapter 4. In Chapter 4, activity in left temporal cortex was higher for unrelated than related and identical distractors, whereas the reverse was observed over frontal brain areas (i.e., related larger than unrelated and identical), in line with the naming RTs. In Chapter 7, activity in the left temporal cortex was also increased for unrelated relative to related and identical distractors, whereas the RTs showed the typical interference patterns. Here, activity in a domain-general portion of the anterior cingulate cortex was larger for related than for identical distractors.

It has been argued that the finding of lower activity for related picture-word pairs in areas associated with lexical memory (i.e., left temporal areas) is incompatible with the finding of longer RTs in this condition (e.g., Blackford *et al.*, 2012; de Zubicaray *et al.*, 2013). However, this argument seems to neglect not only previous formulations of the competition hypothesis (Roelofs & Hagoort, 2002; Roelofs, 2003; Roelofs & Piai, 2011), but also the inherent structure of semantic memory (see e.g., Badre & Wagner, 2007). When a picture-word stimulus is presented, activation from the pictured concept and from the word spread through the lexical-semantic network. If the picture and the word are from the same semantic category, the pictured object and the word will activate overlapping parts of the network, which could explain why the related picture-word pairs in Chapters 4 and 7 showed less brain activity in left temporal cortex relative to unrelated pairs (see also de Zubicaray *et al.*, 2013).

Based on the organisation principles of memory that "calls to memory will often result in the retrieval of more associated information than is relevant to the current task" (Badre & Wagner, 2007, p. 2885), the memory control literature has postulated a selection mechanism that is required in cases of competing retrieved representations (e.g., Badre & Wagner, 2002; Badre *et al.*, 2005; Badre & Wagner, 2007). This selection process relies on goal-maintenance processes to provide top-down biasing for the task-relevant representation (e.g., Miller & Cohen, 2001; Thompson-Schill *et al.*, 1997). This type of function has been mostly associated with the prefrontal cortex (e.g., Badre & Wagner, 2007; Miller & Cohen, 2001; Roelofs *et al.*, 2006; Thompson-Schill *et al.*, 1997), whereas the anterior cingulate cortex in particular has been proposed to provide the top-down regulation necessary for selectively enhancing the activation of the relevant response (Roelofs *et al.*, 2006). The findings from Chapters 4 and 7 of lower left temporal activity for related distractors along with longer naming RTs and higher frontal activity fit well with the postulated mechanisms operating in (the control over) memory retrieval.

8.2.2 The timing of processes: some remaining issues

In Chapter 2, I observed that the semantic interference effect was absent in immediate naming when participants engaged in simultaneous task decisions (cf. Besner & Care,

2003; Janssen *et al.*, 2008). To explain the absence of this effect, an account in terms of absorption into slack was proposed. I argued that semantic interference could be absent in immediate naming depending on the relative speed of picture naming and task-decision processes. Based on estimates of the timing of task choice (Paulitzki *et al.*, 2009), I assumed that a task decision could be completed around 200-300 ms after cue presentation. Furthermore, based on timing estimates for word production (Indefrey & Levelt, 2004), I assumed that lexical selection in picture naming would be completed around 250 ms after picture presentation. Thus, on a large proportion of the trials, lexical selection could be completed before a task decision had been made, explaining the absence of the semantic interference effect.

However, the assumption that lexical selection is completed 250 ms after picture presentation, as presented in the upper panel of Figure 1.4, may only hold for standard picture naming. As I argued in Chapters 1, 4, and 6, the longer RTs in picture-word interference experiments call for a rescaling of the originally proposed estimates (see also Indefrey, 2011). A rescaled estimate of lexical selection, presented in the lower panel of Figure 1.4, places lexical selection roughly at 270 ms post-picture onset. In line with this rescaled estimate, in Chapter 6, I observed that distractor words modulated electrophysiological responses starting around 250 ms after picture onset. This latter claim is not in line with the assumption proposed in Chapter 2 that lexical selection can be completed around 250 ms post-picture onset and may, therefore, be absorbed into slack created by task-decision processes. In addition, the assumption regarding the duration of task-decision processes may also be problematic. Although the estimates provided by Paulitzki et al. (2009) remain the best guess one can make, no subsequent progress has been made in delineating processes involved in task decisions, let alone their time course. Taking these considerations together, a reanalysis and possible reinterpretation of the task decision findings in immediate naming (Chapter 2) may be warranted.

A small scale meta-analysis

In an experiment, we calculate the mean effect of interest based on a sample of our population. This mean is meant as an estimation of the true population mean. However, estimations are subjective to error. Fortunately, we can calculate the "worst-case scenario" for our estimate, that is, the largest likely estimation error. This measure is the so-called *margin of error* of the sample estimation (Cumming, 2012). It is calculated using the following formula:

$$t_{.95}(\text{N-1}) * s/\sqrt{N}$$

for a 95% confidence interval, where N is the sample size and s is the standard deviation of the sample.

Smaller margins of error, of course, indicate a better estimation of the true effect in the population. I calculated the margin of error for the semantic interference effect for five chapters of this dissertation, for the study of Mädebach et al. (2011)[1], and

[1]I am very grateful to Andreas Mädebach for granting me access to these data.

for the study of Piai et al. (submitted)[2]. The results are shown in Table 8.1 for the picture-word interference studies in this dissertation not using a task-decision paradigm (upper part) and for the four available studies using the task-decision paradigm (lower part). With respect to the semantic effect in picture-word interference, the margin of error is relatively small (12 ms on average; upper part of Table 8.1). For the studies with a task decision (lower part of Table 8.1), the margin of error is larger on average (more than 20 ms). Thus, the estimates of the semantic interference effect measured with this procedure are much less precise than those measured with the standard picture-word interference paradigm.

Table 8.1: Margin of error, response time (RT) differences, and sample size for the studies discussed. All values in milliseconds. RT difference is calculated as mean RT related - mean RT unrelated. Exp = Experiment.

Study	margin of error	RT difference	sample size
Chapter 2: Exp 1, immediate naming	15	39	18
Chapter 3: Exp 2, poorly visible	10.5	17	16
Chapter 3: Exp 2, clearly visible	8.5	13	16
Chapter 4	10	17	17
Chapter 6	9.5	26	20
Chapter 7	18	25	17
Mädebach et al. (2011): Exp 5	18	11	32
Chapter 2: Exp 2, immediate naming	15	10	28
Piai et al. (submitted): Exp 1, 0-ms SOA	25	12	20
Piai et al. (submitted): Exp 2, 0-ms SOA	23	15	20

Fortunately, there is something one can do in the face of such a large imprecision: combining evidence from different studies. By using meta-analysis, even on a small scale, an impressive increase in the estimation of effects can be achieved (see for extensive discussion Cumming, 2012). For comparison, I used picture-word interference studies with and without task decision. First, I conducted a meta-analysis of the suitable studies from this dissertation (i.e., no dual tasking or task decisions), presented in the upper part of Table 8.1, which I take to be representative for the semantic interference effect in my work. I also conducted a meta-analysis for the four task-decision studies with relatively imprecise estimates of the semantic interference effect (studies of the lower part of Table 8.1). These meta-analyses were performed with the software package Comprehensive

[2]In Piai et al. (submitted), participants decided on a trial-by-trial basis whether to name the picture or read aloud the distractor word depending on the pitch of a tone, which was presented simultaneously with or before pictureword onset. The data used here comprise only the trials in which the tone and the picture-word stimuli were presented simultaneously. See also Piai and Roelofs (2013) for an additional report of these data.

Meta Analysis[3].

The effect size measure in all studies was the mean RT difference between the related and unrelated conditions. Following common practice, the inverse of the effect size variance was used to weight the studies. A random effects model was used to account for heterogeneity and effect size variance amongst the studies. The results of these small scale meta-analyses are shown in Figure 8.1 for the six studies without task decision (upper part) and the four studies with task decision (lower part). Each data point represents a study, for which the semantic interference effect is shown as a square with its corresponding 95% confidence interval. The size of the square indicates the weight of the study in the meta-analysis, with larger weights given to studies with less variance. The vertical bars provide guidelines for the magnitude of the effect. The diamond displays the point and interval estimates of the meta-analysis results.

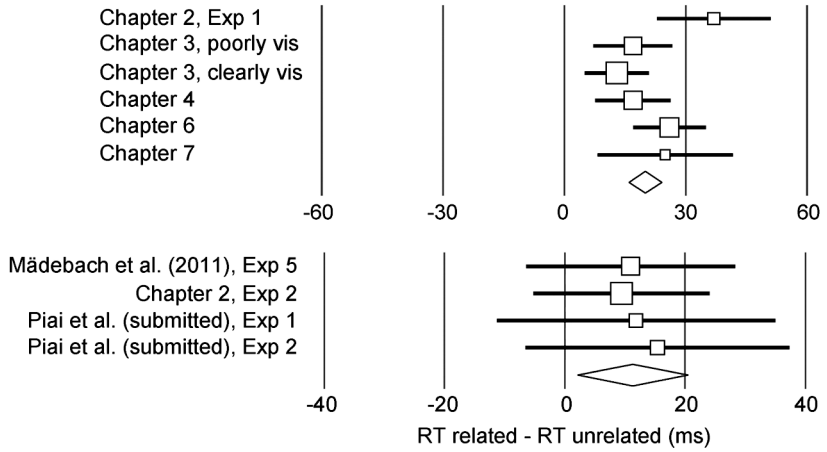

Figure 8.1: Meta-analysis of six picture-word interference studies without task decision (upper panel) and four studies with task decision (lower panel). For Chapter 2, Experiments 1 and 2 concern immediate naming. Chapter 3 concerns Experiment 2. Piai et al. (submitted) concerns the 0-ms SOA. Exp = Experiment; vis = visible.

For the studies without task decision, the estimated effect is 21 ms (interval [15, 28]). For the four task-decision studies, the estimated effect is 11 ms (interval [2,20]).

In Chapter 2, I concluded that the semantic interference effect is absent in picture-word interference with task decision because it is absorbed into slack. Indeed, each study from the lower part of Table 8.1 separately reported a non-significant semantic interference effect with task decision. The meta-analysis results indicate, however, that the effect is not completely absent, a finding that calls for a reinterpretation of the results

[3]Borenstein M, Hedges L, Higgins J, Rothstein H. Comprehensive Meta-analysis Version 2, Biostat, Englewood NJ (2005)

for immediate naming of Chapter 2.

Under the hypothesis that the semantic interference effect is fully absorbed into slack created by task decision, the difference between the related and unrelated conditions should be somewhere around 0. Accordingly, the estimated effect, represented as the diamond in the lower part of Figure 8.1, should be centred around 0 ms. Conversely, if semantic interference is not affected by simultaneous task decision, then the semantic interference effect should be similar with or without task decision (and the diamonds of Figure 8.1 should be at a similar location). Clearly, for as far as the meta-analyses can inform us, the estimated effect with task decision is smaller than the general semantic interference effect, but it is still present.

Following the arguments of Chapters 2 and 5, these results suggest that the semantic interference effect is not fully absorbed into slack. The effect remains, nevertheless, smaller than the often observed interference effect of 20-40 ms. This means that only part of the effect is absorbed, a claim that would be more in line with the rescaled timing estimate of lexical selection roughly at 270 ms post-picture onset.

In sum, the small scale meta-analysis provides new insights into previously unresolved issues. Here, I conclude that only part of the semantic interference effect is absorbed into slack created by task decision. These explanations remain, of course, tentative. However, the meta-analysis suggests that experimental paradigms that are susceptible to large sampling variability (presumably due to strong attentional effects) may not provide the ideal data to adjudicate between different accounts of lexical selection.

8.2.3 The electrophysiology of word production: some open questions

In both Chapters 4 and 6, I examined oscillatory activity associated with performance in picture-word interference. In Chapter 4, distractors differentially modulated the event-related field (ERF) and the oscillatory power in the theta band (ERFs: unrelated > related > identical; theta power: related > unrelated > identical). These modulations were most prominent in a time window between 400-650 ms. In Chapter 6, the event-related potentials differed between the identical, on the one hand, and the related and unrelated conditions, on the other hand, from 250 ms onwards. The semantic interference effect, in turn, was reflected in beta power between 230-370 ms (related > unrelated). Thus, the oscillatory activity in these two studies does not seem to provide a converging pattern for the semantic interference effect.

Various factors could have caused this discrepancy. Firstly, the EEG data from Chapter 6 was segmented into epochs lasting only until 500 ms post-stimulus to avoid the contamination of the signal by speech artefacts. For the MEG data in Chapter 4, speech artefacts were better identified and characterised and, therefore, there was little concern with respect to contamination of the signal. Thus, longer data segments could be analysed, extending up to 1 s post-stimulus. As a consequence, the time-frequency representation of Chapter 6 only extended until 400 ms, whereas the time-frequency

representations of Chapter 4 extended up to 800 ms and the power modulations were identified starting around 400 ms. Secondly, the two studies differed with respect to the role of response-set membership. In Chapter 3, I showed that distractors in the response set may provide stronger input than distractors not in the response set. Distractors in Chapter 4 were part of the response set whereas in Chapter 6, they were not. Finally, the technique used to record brain activity in Chapter 4 was MEG, whereas EEG was used in Chapter 6. These two techniques differ in their sensitivity to the orientation of underlying brain sources, resulting not only in the possibility that a source is undetected with MEG, but also in differences in the signal-to-noise ratio between the two measures due to selective cancellation of signals (e.g., Ahlfors *et al.*, 2010). How all these factors may have contributed to the difference in those results remains to be seen. We have only started to apply electrophysiological techniques to the study of language production, so cumulative knowledge from (future) studies will be needed to elucidate these open questions.

8.3 General Conclusions

In the studies described in the present dissertation, I examined some challenges to the hypothesis that co-activated words compete for selection and, therefore, influence how long it takes to select a target word. A key finding in support of the competition hypothesis, the semantic interference effect, has received an alternative explanation in the literature, formulated as the *response exclusion hypothesis* (a post-lexical selection account). I argued that this alternative hypothesis lacks theoretical specification and, more importantly, empirical support to replace the competition hypothesis. A second challenge to the competition hypothesis was posed by findings suggesting a pre-lexical selection locus of the semantic interference effect. However, this alternative hypothesis has also failed to survive rigorous empirical testing. Therefore, I conclude that the lexical competition hypothesis (still) provides the best explanatory framework for semantic interference effects in spoken word production.

Many questions still remain, of course. The increasing use of techniques such as EEG, MEG, and fMRI will hopefully add further neurobiological constraints to cognitive theories of language production, whilst also highlighting future avenues to understand the language production ability in the broader context of how cognitive processes are implemented in the brain. Finally, new insights into our ability to speak can be gained by incorporating into our theories notions that go beyond the language domain, and the present work provides some evidence for the value of such an approach. I end here, but this may be just the beginning.

APPENDIX A

Stimulus lists

Table A.1: Materials from Experiments 1 and 3 of Chapter 2 (English translations between parentheses). Verification words apply to Experiment 1 only.

		Distractor		*Verification*
Category	Picture Name	Related	Unrelated	Different
Animals	zwaan (swan)	schildpad	rok	auto/fiets
	schildpad (turtle)	zwaan	beker	arm/been
	konijn (rabbit)	hert	arm	trui/jas
	hert (deer)	konijn	bureau	fabriek/molen
Clothing	trui (sweater)	rok	dolk	hert/zwaan
	rok (skirt)	trui	zwaan	kasteel/kerk
	hemd (singlet)	jas	oor	dolk/zwaard
	jas (jacket)	hemd	kasteel	schildpad/konijn
Transportation	fiets (bicycle)	trein	kast	kanon/pistool
	trein (train)	fiets	kerk	beker/bord
	auto (car)	vliegtuig	konijn	tafel/kast
	vliegtuig (airplane)	auto	glas	rok/hemd
Buildings	molen (mill)	kasteel	kan	bureau/bed
	kasteel (castle)	molen	jas	neus/oor
	fabriek (factory)	kerk	neus	glas/kan
	kerk (church)	fabriek	been	vliegtuig/trein
Weapons	dolk (dagger)	zwaard	trui	beker/bord
	zwaard (sword)	dolk	tafel	auto/fiets
	kanon (cannon)	pistool	bord	jas/trui
	pistool (gun)	kanon	bed	molen/kerk
Kitchenware	beker (cup)	kan	schildpad	dolk/zwaard
	kan (pitcher)	beker	molen	neus/oor
	glas (glass)	bord	vliegtuig	been/arm
	bord (plate)	glas	kanon	hemd/rok
Furniture	tafel (table)	bed	zwaard	konijn/schildpad
	kast (wardrobe)	bureau	fiets	kanon/pistool
	bed (bed)	tafel	pistool	kasteel/fabriek
	bureau (desk)	kast	hert	vliegtuig/trein
Body parts	arm (arm)	neus	trein	tafel/kast
	neus (nose)	arm	fabriek	bureau/bed
	been (leg)	oor	auto	glas/kan
	oor (ear)	been	hemd	hert/zwaan

Table A.2: Materials from Experiment 2 of Chapter 2 (English translations between parentheses).

Picture Name	Related Distractor	Unrelated Distractor
auto (car)	vrachtwagen (truck)	fontein
bed (bed)	sofa (couch)	zwabber
been (leg)	elleboog (elbow)	sinaasappel
berg (mountain)	vulkaan (volcano)	walvis
bezem (broom)	zwabber (swab)	sofa
brood (bread)	cracker (cracker)	sigaar
dobbelsteen (dice)	kaart (cards)	thermos
dolfijn (dolphin)	walvis (whale)	vulkaan
eikel (acorn)	kastanje (chestnut)	veerpont
fles (bottle)	thermos (flask)	kaart
fluit (flute)	gitaar (guitar)	scheen
hand (hand)	scheen (shin)	gitaar
hark (rake)	schep (spade)	wenkbrauw
harp (harp)	viool (violin)	lever
hart (heart)	lever (liver)	viool
hond (dog)	konijn (rabbit)	ballon
kanon (cannon)	pistool (pistol)	enkel
kerk (church)	moskee (mosque)	arend
kikker (frog)	hagedis (lizard)	bliksem
mond (mouth)	wenkbrauw (brow)	schep
oog (eye)	enkel (ankle)	pistool
paard (horse)	geit (goat)	boor
peer (pear)	sinaasappel (orange)	elleboog
pijp (pipe)	sigaar (cigar)	cracker
put (well)	fontein (fountain)	vrachtwagen
regen (rain)	bliksem (lightning)	hagedis
schoen (shoe)	want (glove)	worm
slak (snail)	worm (worm)	want
spijker (nail)	schroef (screw)	koets
tafel (table)	bank (bench)	ui
trein (train)	koets (carriage)	schroef
uil (owl)	arend (eagle)	moskee
vaas (vase)	urn (urn)	mossel
vis (fish)	mossel (clam)	urn
vlieger (kite)	ballon (balloon)	konijn
vliegtuig (airplane)	veerpont (ferry)	kastanje
wortel (carrot)	ui (onion)	bank
zaag (saw)	boor (drill)	geit
zon (sun)	komeet (comet)	gans
zwaan (swan)	gans (goose)	komeet

Table A.3: Materials from Experiment 1 of Chapter 3 (English translations between parentheses).

Picture Name	Related Distractor	Unrelated Distractor
aardbei (strawberry)	banaan (banana)	trompet
arm (arm)	neus (nose)	vliegtuig
auto (car)	vliegtuig (airplane)	konijn
gitaar (guitar)	trompet (trumpet)	schommel
glijbaan (slide)	schommel (swing)	zaag
hamer (hammer)	zaag (saw)	banaan
hert (deer)	konijn (rabbit)	beker
kaas (cheese)	worst (sausage)	sigaret
kan (pitcher)	beker (cup)	neus
kast (wardrobe)	bureau (desk)	rok
maan (moon)	zon (sun)	lepel
molen (mill)	kasteel (castle)	bureau
pijp (pipe)	sigaret (cigarette)	worst
pistool (gun)	kanon (cannon)	kasteel
trui (sweater)	rok (skirt)	kanon
vork (fork)	lepel (spoon)	zon

Table A.4: Materials from Experiment 2 of Chapter 3 (English translations between parentheses).

Category	Picture Name	Related Distractor	Unrelated Distractor
Animals	hert (deer)	konijn	bureau
	konijn (rabbit)	hert	arm
	zwaan (swan)	schildpad	rok
	schildpad (turtle)	zwaan	beker
Clothing	jas (jacket)	hemd	kasteel
	hemd (singlet)	jas	oor
	rok (skirt)	trui	zwaan
	trui (sweater)	rok	dolk
Transportation	auto (car)	vliegtuig	konijn
	vliegtuig (airplane)	auto	glas
	trein (train)	fiets	kerk
	fiets (bicycle)	trein	kast
Buildings	kerk (church)	fabriek	been
	fabriek (factory)	kerk	neus
	molen (mill)	kasteel	kan
	kasteel (castle)	molen	jas
Weapons	dolk (dagger)	zwaard	trui
	zwaard (sword)	dolk	tafel
	kanon (cannon)	pistool	bord
	pistool (gun)	kanon	bed
Kitchenware	kan (pitcher)	beker	molen
	beker (cup)	kan	schildpad
	bord (plate)	glas	kanon
	glas (glass)	bord	vliegtuig
Furniture	bed (bed)	tafel	pistool
	tafel (table)	bed	zwaard
	bureau (desk)	kast	hert
	kast (wardrobe)	bureau	fiets
Body parts	neus (nose)	arm	fabriek
	arm (arm)	neus	trein
	been (leg)	oor	auto
	oor (ear)	been	hemd

Table A.5: Materials from the experiment of Chapter 4 (English translations between parentheses).

Picture name	Semantically Related Distractor	Semantically Unrelated Distractor
ananas (pineapple)	banaan	kasteel
appel (apple)	peer	dolk
arm (arm)	neus	trein
auto (car)	bus	konijn
banaan (banana)	ananas	trui
bed (bed)	tafel	pistool
been (leg)	oor	auto
beker (cup)	kan	geit
bord (plate)	glas	kanon
bureau (desk)	kast	hert
bus (bus)	auto	glas
dolk (dagger)	zwaard	appel
fabriek (factory)	kerk	neus
fiets (bicycle)	trein	kast
geit (goat)	zwaan	beker
glas (glass)	bord	bus
hemd (shirt)	jas	oor
hert (deer)	konijn	bureau
jas (jacket)	hemd	peer
kan (jug)	beker	molen
kanon (cannon)	pistool	bord
kast (wardrobe)	bureau	fiets
kasteel (castle)	molen	ananas
kerk (church)	fabriek	been
konijn (rabbit)	hert	arm
molen (mill)	kasteel	kan
neus (nose)	arm	fabriek
oor (ear)	been	hemd
peer (pear)	appel	jas
pistool (pistol)	kanon	bed
rok (skirt)	trui	zwaan
tafel (table)	bed	zwaard
trein (train)	fiets	kerk
trui (sweater)	rok	banaan
zwaan (swan)	geit	rok
zwaard (sword)	dolk	tafel

Table A.6: Materials used in Experiments 2, 3, 4, and 5 of Chapter 5 (English translations between parentheses).

Category	Picture Name	Related Distractor	Unrelated Distractor
Animals	hert (deer)	konijn	bureau
	konijn (rabbit)	hert	arm
	zwaan (swan)	geit	rok
	geit (goat)	zwaan	beker
Clothing	jas (jacket)	hemd	kasteel
	hemd (singlet)	jas	oor
	rok (skirt)	trui	zwaan
	trui (sweater)	rok	dolk
Transportation	auto (car)	bus	konijn
	bus (bus)	auto	glas
	trein (train)	fiets	kerk
	fiets (bicycle)	trein	kast
Buildings	kerk (church)	fabriek	been
	fabriek (factory)	kerk	neus
	molen (mill)	kasteel	kan
	kasteel (castle)	molen	jas
Weapons	dolk (dagger)	zwaard	trui
	zwaard (sword)	dolk	tafel
	kanon (cannon)	pistool	bord
	pistool (gun)	kanon	bed
Kitchenware	kan (pitcher)	beker	molen
	beker (cup)	kan	geit
	bord (plate)	glas	kanon
	glas (glass)	bord	bus
Furniture	bed (bed)	tafel	pistool
	tafel (table)	bed	zwaard
	bureau (desk)	kast	hert
	kast (wardrobe)	bureau	fiets
Body parts	neus (nose)	arm	fabriek
	arm (arm)	neus	trein
	been (leg)	oor	auto
	oor (ear)	been	hemd

Table A.7: Materials used in the experiment of Chapter 6 (English translations between parentheses).

Picture Name	Categorically Related Distractor	Unrelated Distractor
High frequency		
arm (arm)	heup (hip)	koe
bed (bed)	kast (wardrobe)	kaars
been (leg)	duim (thumb)	appel
broek (trousers)	rok (skirt)	pan
fiets (bicycle)	kar (cart)	hoed
fles (bottle)	pot (pot)	horloge
geweer (rifle)	zwaard (sword)	bal
huis (house)	kasteel (castle)	trommel
jas (jacket)	hemd (shirt)	duif
jurk (dress)	trui (sweater)	lepel
kaas (cheese)	ham (ham)	pistool
kat (cat)	varken (pig)	mes
kerk (church)	fabriek (factory)	pop
koffer (suitcase)	tas (bag)	piano
maan (moon)	zon (sun)	kom
oog (eye)	pols (wrist)	wortel
oor (ear)	teen (toe)	paleis
paard (horse)	beer (bear)	tempel
schoen (shoe)	laars (boot)	konijn
tafel (table)	fauteuil (armchair)	aap
Low frequency		
banaan (banana)	appel (apple)	heup
beker (cup)	lepel (spoon)	duim
dolk (dagger)	pistol (gun)	hemd
egel (hedgehog)	konijn (rabbit)	zwaard
fakkel (torch)	kaars (candle)	pols
giraffe (giraffe)	koe (cow)	kast
gitaar (guitar)	trammel (drum)	kasteel
hert (deer)	aap (monkey)	tas
igloo (igloo)	temple (temple)	teen
kan (jug)	mes (knife)	beer
ketel (kettle)	pan (pan)	fauteuil
molen (mill)	paleis (palace)	trui
muts (tuque)	hoed (hat)	fabriek
tol (spintop)	pop (doll)	varken
tomaat (tomato)	wortel (carrot)	rok
trompet (trumpet)	piano (piano)	ham
vlieger (kite)	bal (ball)	pot
vork (fork)	kom (bowl)	zon
wekker (alarm clock)	horologe (watch)	kar
zwaan (swan)	duif (pigeon)	laars

Table A.8: Materials used in the experiment of Chapter 7 (English translations between parentheses).

Category	Picture Name	Related Distractor	Unrelated Distractor
Animals	hert (deer)	konijn	piano
	konijn (rabbit)	hert	drumstel
	zwaan (swan)	geit	bus
	geit (goat)	zwaan	fluit
Clothing	jas (jacket)	hemd	molen
	hemd (singlet)	jas	tafel
	rok (skirt)	trui	neus
	trui (sweater)	rok	banaan
Transportation	auto (car)	bus	kanon
	bus (bus)	auto	konijn
	trein (train)	fiets	kast
	fiets (bicycle)	trein	trui
Buildings	kerk (church)	fabriek	zwaan
	fabriek (factory)	kerk	zwaard
	molen (mill)	kasteel	dolk
	kasteel (castle)	molen	oor
Weapons	dolk (dagger)	zwaard	arm
	zwaard (sword)	dolk	been
	kanon (cannon)	pistool	bed
	pistool (gun)	kanon	kan
Kitchenware	kan (pitcher)	beker	fabriek
	beker (cup)	kan	pistool
	bord (plate)	glas	rok
	glas (glass)	bord	kerk
Furniture	bed (bed)	tafel	gitaar
	tafel (table)	bed	kasteel
	bureau (desk)	kast	geit
	kast (wardrobe)	bureau	molen
Body parts	neus (nose)	arm	auto
	arm (arm)	neus	peer
	been (leg)	oor	appel
	oor (ear)	been	beker
Fruit	ananas (pineapple)	banaan	hert
	appel (apple)	peer	fiets
	banaan (banana)	ananas	trein
	peer (pear)	appel	hemd
Music instruments	drumstel (drums)	gitaar	bureau
	gitaar (guitar)	drumstel	jas
	fluit (flute)	piano	bord
	piano (piano)	fluit	glas

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Nederlandse Samenvatting

Sprekers van een taal slagen er heel goed in om snel en nauwkeurig woorden uit hun geheugen op te halen als ze spreken, een proces dat 'lexicale selectie' wordt genoemd. Als sprekers een woord selecteren om een concept uit te drukken, dan wordt niet alleen het doelwoord actief in het geheugen (bijv. 'hond') maar ook andere woorden geassocieerd met dat concept (bijv. 'kat', 'konijn', en andere dieren). Volgens een prominente theorie van taalproductie, de competitie-theorie, gaan deze actieve woorden met elkaar in competitie. Door deze competitie is de tijd die verstrijkt voordat het doelwoord is geselecteerd afhankelijk van het activatieniveau van het doelwoord ten opzichte van het activatieniveau van alle andere actieve woorden. Kortom, lexicale selectie is volgens deze theorie een competitief proces en de hoeveelheid competitie bepaalt voor een groot deel hoe lang het selectieproces kan duren. Competitie in lexicale selectie staat centraal in dit proefschrift.

Evidentie voor de competitie-theorie komt van een paradigma waarin plaatjes benoemd moeten worden terwijl er interferentie is van afleidende woorden (plaatje-woord interferentie). Proefpersonen worden gevraagd een plaatje zo snel en accuraat mogelijk te benoemen. Het plaatje wordt gepresenteerd met een woord erbovenop, het zogenoemde afleidende woord. Dit woord kan semantisch gerelateerd zijn aan het plaatje (bijv. een plaatje van een hond met het woord 'kat', de semantische conditie) of ongerelateerd (bijv. een plaatje van een hond met het woord 'pen', de ongerelateerde conditie). Tientallen jaren onderzoek heeft aangetoond dat proefpersonen trager en minder accuraat zijn in de semantische conditie dan in de ongerelateerde conditie. Dat wil zeggen, het kost meer moeite om hetzelfde plaatje te benoemen als het afleidende woord semantisch gerelateerd is aan het plaatje. Dit effect is bekend als 'semantische interferentie'. Het semantische interferentie effect vormt de belangrijkste bron van evidentie voor de theorie dat lexicale selectie competitief is: Woorden die semantisch gerelateerd zijn (bijv. de plaatjesnaam 'hond' en het afleidende woord 'kat') en tegelijkertijd aangeboden worden, blijven elkaar versterken omdat ze aan elkaar gekoppeld zijn in ons geheugen. Hierdoor is het verschil in activatieniveau tussen het doelwoord 'hond' en het afleidende woord 'kat' niet zo groot, waardoor de selectie van 'hond' moeizamer gaat (dat wil zeggen, het duurt langer en is minder nauwkeurig). Kortom, volgens de competitie-theorie ontstaat het semantische interferentie effect tijdens lexicale selectie.

Recent onderzoek zet echter vraagtekens bij deze competitie-theorie. In recente literatuur bestaan twee alternatieven voor de stelling dat het semantische interferentie effect ontstaat tijdens lexicale selectie. Een belangrijk deel van dit proefschrift houdt zich bezig met de evidentie voor deze alternatieve voorstellen. Hoofdstukken 2, 3 en 4 hebben de alternatieve theorie onderzocht die stelt dat het semantische interferentie effect ontstaat na lexicale selectie, namelijk nadat de motorprogramma's voor het uitspreken van de plaatjesnaam en van het afleidende woord zijn gevormd. Volgens deze theorie wordt het motorprogramma voor het uitspreken van het afleidende woord eerder gevormd en geplaatst in een buffer. Hierdoor moet het programma voor het uitspreken van de plaatjesnaam wachten totdat de buffer wordt geleegd voordat het plaatje be-

noemd kan worden. Deze theorie wordt de 'respons-exclusie hypothese' genoemd. In hoofdstukken 5 en 6 heb ik onderzocht of er evidentie is voor het alternatieve scenario dat het semantische interferentie effect ontstaat voordat het doelwoord geselecteerd wordt. In hoofdstuk 7 heb ik onderzocht of het selectieproces in woordproductie gerelateerd kan worden aan andere selectieprocessen in het brein die niet te maken hebben met taal. In alle hoofdstukken worden onderzoeken besproken die gebruik hebben gemaakt van het plaatje-woord paradigma. Hieronder beschrijf ik elk hoofdstuk in meer detail.

In hoofdstuk 2 werd een deel van de evidentie voor de respons-exclusie hypothese bekeken. Een studie uit 2011 (Janssen et al.) heeft aangetoond dat het semantische interferentie effect ook voorkomt als proefpersonen de plaatjebenoemingsrespons uitstellen. In die studie werden eerst alleen de plaatjes gepresenteerd, waardoor lexicale selectie al plaats kon vinden in de afwezigheid van het afleidende woord. Pas later kwam het afleidende woord op het scherm, wat aangaf dat het plaatje benoemd moest worden. Als lexicale selectie al plaatsvindt zonder de presentatie van het afleidende woord, zou er geen competitie moeten optreden en zou de competitietheorie geen semantische interferentie effect voorspellen, in tegenstelling tot de bevindingen van Janssen et al. Deze bevinding werd in drie experimenten van hoofdstuk 2 grondig onderzocht, maar in geen van de drie experimenten werden de effecten gerepliceerd. Integendeel, alle drie de experimenten lieten zien wat de competitie-theorie voorspelt, namelijk, geen semantische interferentie effect als lexicale selectie plaatsvindt in de afwezigheid van het afleidende woord. Deze bevindingen ondersteunen de competitie-theorie en verwerpen de respons-exclusie hypothese.

In hoofdstuk 3 werd een ander aspect van de evidentie voor de respons-exclusie hypothese bekeken. Finkbeiner en Caramazza (2006) lieten zien dat er geen semantische interferentie optreedt als het afleidende woorde zo kort wordt aangeboden dat proefpersonen zich er niet bewust van kunnen worden. Volgens de respons-exclusie hypothese wordt deze bevinding verklaard doordat er geen motorprogramma gevormd kan worden als het afleidende woord niet bewust wordt waargenomen. Hierdoor wordt het afleidende woord niet in de buffer geplaatst waardoor de plaatje-benoemingsrespons niet hoeft te wachten. In hoofdstuk 3 werd het experiment van Finkbeiner en Caramazza (2006) in twee experimenten overgedaan maar met afleidendwoord-invoersterkte als extra manipulatie. Deze experimenten lieten zien dat het al dan niet optreden van semantische interferentie niet afhangt van bewustzijn, zoals beweerd door Finkbeiner en Caramazza, maar eerder van de activatiesterkte van het afleidende woord. Afleidende woorden die genoeg geactiveerd zijn, komen in competitie met de plaatjesnaam, waardoor semantische interferentie ontstaat maar afleidende woorden die niet genoeg invoer-sterkte hebben, komen niet in competitie met de plaatjesnaam waardoor geen semantische interferentie wordt gevonden. Deze verklaring vormt een alternatieve verklaring voor de eerdere bevindingen waardoor de competitie-theorie niet verworpen hoeft te worden.

In hoofdstuk 4 werd magnetoencefalografie (MEG) gebruikt om lexicale activatie en competitie te karakteriseren in termen van breinresponses. Ik onderzocht zowel 'phase-locked' (gebeurtenis-gerelateerde velden) als 'niet phase-locked' breinresponses. In linkertemporale breingebieden die in de literatuur gerelateerd worden aan taal- en

geheugenprocessen was het gebeurtenis-gerelateerde veld groter voor plaatjes in de ongerelateerde conditie dan in de semantische conditie. Deze bevinding kan verklaard worden door processen die te maken hebben met geheugen-ophaalprocessen: in de semantische conditie behoren zowel de plaatjesnaam als het afleidende woord tot dezelfde categorie (bijv. 'hond' en 'kat', beide zijn dieren) terwijl in de ongerelateerde conditie het plaatje en het afleidende woord geen eigenschappen in het geheugen delen (bijv. 'hond' en 'pen' hebben geen associatieve kenmerken). Geheugen-ophaalprocessen zijn dus moeizamer in de ongerelateerde conditie. In linkerfrontale breingebieden die in de literatuur geassocieerd worden met controle processen was de niet phase-locked breinactiviteit sterker voor plaatjes in de semantische conditie dan in de ongerelateerde conditie, in lijn met de gedragseffecten. Deze breinactiviteit is mogelijk gerelateerd aan het competitieproces. Deze bevindingen vormen belangrijke evidentie voor een meervoudige implementatie van lexicale selectie in het brein.

In hoofdstuk 5 werd de stelling onderzocht dat het semantische interferentie effect ontstaat vóór lexicale selectie. Met een paradigma bestaande uit twee taken rapporteerden Dell'Acqua et al. (2007) een patroon van effecten dat alleen compatibel was met een verklaring dat deze stelling bevestigde. Zes experimenten werden uitgevoerd om dat patroon van effecten te onderzoeken, maar geen van de zes experimenten konden het eerdere patroon repliceren. Integendeel, alle zes de experimenten waren in lijn met de stelling dat het semantische interferentie effect ontstaat tijdens lexicale selectie, wat verdere ondersteuning vormt voor de competitie-theorie.

Hoofdstuk 6 gebruikte elektroencefalografie (EEG) om het tijdsverloop van interferentie effecten in het plaatje-woord interferentie paradigma in relatie tot het tijdsverloop van het lexicale selectieproces te bestuderen. Hiervoor werd het woordfrequentie-effect gebruikt omdat dit effect bekend staat als een aanwijzing voor lexicale selectieprocessen. Rondom eenzelfde tijdsvenster werd breinactiviteit gemoduleerd als een functie van zowel woordfrequentie (het woordfrequentie-effect) als afleidend woord. Deze bevindingen kunnen verklaard worden door de hypothese dat afleidend-woordeffecten, en dus het semantische interferentie effect, tijdens lexicale selectie ontstaan. Deze bevindingen zijn echter niet compatibel met de hypothese dat het semantische interferentie effect ontstaat voor lexicale selectie.

In hoofdstuk 7 werd functionele kernspintomografie (fMRI) gebruikt om de aandachtscontrole processen tijdens lexicale selectie in woordproductie te vergelijken met aandachtscontrole processen in respons-selectie in domeinen buiten taal. Hiervoor werden drie taken gebruikt die varieerden in de graad van competitie tussen mogelijke responses. Twee van deze taken waren talige taken die een vocale respons vereisten (plaatje-woord interferentie en de Stroop taak, waarbij de kleur van kleurwoorden benoemd moet worden) terwijl de derde taak een spatiële taak was die een manuele respons vereiste (Simon taak, waarbij links- of rechtsresponses gegeven moeten worden afhankelijk van de stimuli die links of rechts gepresenteerd worden). In alle drie de taken moeten de responses worden geselecteerd in de aanwezigheid van competitie tussen die responses, een situatie die aandachtscontrole vereist. Een gebied binnen de cortex cingularis anterior (ACC) werd

gevonden dat meer gemeenschappelijke activiteit toonde voor alle taken in de conditie waarbij de meeste aandachtscontrole nodig was. Deze bevindingen suggereren dat de aandachtscontrole processen die een rol spelen tijdens lexicale selectie in woordproductie van algemene aard zijn.

Uit dit proefschrift kunnen we concluderen dat veel van de effecten die de alternatieve theorieën ondersteunden, niet gerepliceerdde kunnen worden. De evidentie voor de twee alternatieve theorieën is matig tot zwak, terwijl de evidentie voor de competitietheorie sterk blijft.

Curriculum Vitae

Vitória Magalhães Piai was born in 1982 in São Paulo, Brazil. After graduating from high school in São Paulo, she started a bachelor's degree in Linguistics at the University of São Paulo in 2000. In 2001, she interrupted her studies to spend one year in Belgium as an exchange student. In 2002, she moved to the Netherlands and started teaching Portuguese as a second language. In September 2004, she restarted her studies at Utrecht University, from which she obtained her bachelor's degree in Linguistics (cum laude) and in Portuguese Language and Culture (cum laude) in 2007. She continued teaching Portuguese and doing translation work until 2007. In the beginning of 2007, she started working as a student-assistant for Prof. Mirjam Ernestus at the Centre for Language Studies at Radboud University Nijmegen and in September of that same year, she started a two-year research master's programme in Cognitive Neuroscience at Radboud University Nijmegen. For her internship, she worked on the comprehension of particle verbs in sentential context using electroencephalography under the supervision of Prof. Rob Schreuder and Dr. Marcel Bastiaansen. She obtained her master's degree in August 2009 (bene meritum) and started her PhD research under the supervision of Prof. Ardi Roelofs and Prof. Herbert Schriefers at the Donders Institute for Brain, Cognition and Behaviour at Radboud University. During her PhD, she worked on lexical selection in spoken word production using behavioural methods, as well as electro- and magnetoencephalography and functional magnetic resonance imaging. In the end of 2013, she was granted a Niels Stensen Fellowship and a Rubicon to work with Prof. Bob Knight and Prof. Nina Dronkers at the University of California, Berkeley. From April 2014 onwards, she will investigate the influence of sentential context on the retrieval of words from memory using electrocorticography on patients with intractable epilepsy and electroencephalography on patients with prefrontal cortex lesion.

Publication List

Piai, V., Roelofs, A., & Schriefers, H. (in press). Locus of semantic interference in picture naming: evidence from dual-task performance. *Journal of Experimental Psychology: Learning, Memory, and Cognition.*

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Roelofs, A., **Piai, V.**, Garrido Rodriguez, G., & Chwilla, D. J. (submitted). Electrophysiology of contextual influences in picture naming: Functional significance of the N400 effect.

Rommers, J., Meyer, A.S., **Piai, V.**, & Huettig, F. (submitted). Constraining the involvement of language production in comprehension: A comparison of object naming and object viewing in sentence context.

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Piai, V., Dahlslätt, K., & Maris, E. (in preparation). The effects of autocorrelation on statistical tests of event-related potentials.

Piai, V., Roelofs, A., Rommers, J., & Maris, E. (in preparation). Oscillatory dynamics of contextually driven spoken word production.

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